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FOREIGN CIVIL AVIATION COMPETITION
1976 SUMMARY AND IMPLICATIONS

by Staff of Systems Analysis Branch
Aeronautical Systems Division
NASA Langley Research Center

Compiled by
William J. Alford, Jr. and Dal V. Maddalon
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665

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16. Abstract A summary assessment was made of foreign civil aviation as it relates to the posture of the United States civil aviation industry. Major findings were: <u>Main competitors</u> .- European Economic Community (EEC) and Union of Soviet Socialist Republics (USSR). <u>Largest commercial market</u> .- Transport aircraft. <u>Current market status and projections</u> .- U.S. currently dominates the civil aviation market but foreign markets show greater growth trends. <u>Competitive comparisons</u> .- Relative 1976 status comparisons are made in technology (aerodynamics, structures and materials, propulsion, avionics, systems, design coordination, and manufacturing); production runs; marketing; and post-sales support. The U.S. generally leads except in aerodynamics and propulsion. <u>Multi-national ventures</u> .- Joint U.S. industry/foreign government development of advanced technology engines is well developed; airframe industry discussions are now underway. <u>Implications</u> .- Although the U.S. is currently preeminent in most areas, this may be only a temporary condition. Past U.S. success in aviation has provided many benefits to the nation. These benefits are <u>danger of being lost</u> .			
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SUMMARY

The results of a summary assessment of foreign civil aviation competition as it relates to the United States posture was undertaken to provide information relating to long-term NASA aeronautical research and technology program planning. Major findings were:

Main competitors. - European Economic Community (EEC)¹ and Union of Soviet Socialist Republics (USSR).

Largest commercial market. - Transport aircraft.

Current market status and projections. - U.S. currently dominates the civil aviation market but foreign markets show greater growth trends. The future market is large and attractive.

Competitive comparisons. - Relative 1976 status comparisons are made in technology (aerodynamics, structures and materials, propulsion, avionics, systems, design coordination, and manufacturing); production runs; marketing; and post-sales support. The U.S. generally leads except in aerodynamics and propulsion.

Potential new projects. - A considerable number have been announced aimed at traditional U.S. markets.

Multi-national ventures. - Joint U.S. industry/foreign government development of advanced technology engines is well developed. From the U.S. viewpoint, multi-national ventures provide some advantages in that large development costs and risks are reduced, and guaranteed access to the foreign partner's market is obtained. Disadvantages foreseen are the creation of future competitors through transfer of U.S. technology and dilution of the employment and sales base.

Implications. - Although the U.S. is currently preeminent in most areas, this may be only a temporary condition. The U.S. aviation industry is currently

¹EEC - France, Federal Republic of Germany, Italy, Belgium, Netherlands, Luxemburg, United Kingdom, Ireland, and Denmark.

in poor financial health and must compete with foreign governments who provide financing to both their manufacturers and their airlines. Past U.S. success in aviation has provided many benefits to the nation. These benefits will not continue unless the U.S. aviation industry can resolve its major problems.

INTRODUCTION

The purpose of this paper is to present a summary assessment of foreign civil aviation competition and to discuss some of the implications relative to the U.S. aviation industry's current and future posture. This work was undertaken in response to a request from the NASA Associate Administrator for Aeronautics and Space Technology to: (1) provide information for long-range aeronautical research and technology program planning, (2) respond to Congressional and government agency questions on NASA activities, and (3) aid the national civil aviation industry which currently faces a number of very serious problems. The importance of foreign competition to long-range R&T program planning is discussed in reference 1.

SOURCES OF DATA AND ACKNOWLEDGEMENTS

The data sources utilized consisted of:

- o Articles from scientific and aviation trade magazines.
- o Aerospace Industries Association statistics and studies.
- o European Economic Community documents.
- o Boeing, Douglas, Lockheed, United Technologies, and General Electric company documents and personal communications.
- o Interviews and trip reports of NASA technical specialists.
- o NASA documents and NASA technical translations of selected foreign publications.
- o USSR "Aviaexport" brochures.
- o Defense Intelligence Agency/USAF reports and personal communications.

To present the study results in unclassified form, some technological comparisons are presented in a generalized format.

Acknowledgment is gratefully made to a number of technical experts from the NASA Langley Research Center - Aeronautics, Structures, and Electronics Directorates - who served as contributors, consultants, and reviewers.

DISCUSSION

Primary Aircraft Market

A variety of aircraft types and major markets have been examined including transports, general aviation, and helicopters. In some instances, it was also necessary to consider military aircraft in order to scope and assess the status and competitiveness of various aeronautical technologies.

Results presented in figure 1 (ref. 2) indicate that from 1961-1975 the dollar value of U.S. transport aircraft deliveries was at least 3- to 4-times larger than that of general aviation and many times larger than helicopter deliveries. Therefore, this paper has concentrated on the transport category. Exports are seen to be increasingly important.

Main Competitors

The study reviewed aerospace industry data from the U.S., EEC, USSR, Japan, and Canada. Detailed data on all nations studied was not always available. However, the data did clearly indicate that the main competitors in the world's aircraft market are the U.S., EEC, and the USSR. This result was reached using data such as sales and employment, jet aircraft manufactured and recent aircraft orders, major airline comparisons, and traffic history and predicted growth.

Sales and employment.- A comparison of aerospace (both civil and military) employment from 1969 to 1973 and sales for 1974 is presented in figure 2 (refs. 2-6) for the main free-world competitors. The three major U.S. airframe manufacturers employ about 45,300 people on civil work, down from 126,000 in 1968. The Russian aerospace industry employs about 900,000 people.

The U.S. level of employment was approximately two and one-half (2-1/2) times larger in 1973 than that of the EEC and many times larger than Canada and Japan. In the case of sales, the difference is even greater. Employment and sales levels of U.S. civil aviation are clearly large contributors to the gross national product.

Jet aircraft deliveries.- A comparison of total jet transport deliveries (as of 1974) for the U.S., EEC, and USSR is presented in table I. These data indicate that the U.S. had orders for 4,613 aircraft as compared to 859 for the EEC during the 1958-1974 time period. The USSR, whose market is primarily limited to the Warsaw Pact nations, had orders for a total of over 1,228 aircraft. Most U.S. aircraft have had sizable production runs which increase the possibility of recovering research and development cost, making profits, and lowering unit price via learning curve economics. In contrast, none of the EEC aircraft have broken the 300-aircraft sales level. Earlier USSR aircraft were generally of low production levels but the more recent YAK-40 has reached the 600 level and is expected eventually to reach levels on the order of 1,400 (ref. 8).

Recent aircraft orders (1974-1975) for U.S. aircraft and the EEC A-300 Airbus are listed in table II (i.e., ref. 7). There were critical declines in nearly

all orders for listed U.S. aircraft from 1974 to 1975 and a significant increase in A-300 orders. This suggests that the EEC - through careful planning, consortium manufacturing, and government financing - may be capable of making in-roads into U.S. markets. Concorde production authorization is presently limited to 16 copies.

Airline comparison.- A comparison of salient statistical characteristics of the competitive communities' major airlines is presented in table III (refs. 2, 6, and 9). The data include percent of state ownership, revenue passenger miles (RPM), passenger traffic, and employment. It should be noted that all of the foreign flag lines are largely state owned and financed. The U.S. had the highest RPM and passenger movements; the USSR, second; EEC, third; Canada, fourth; and Japan, the lowest.

Productivity of the various airlines, as measured by RPM per airline employee, indicates that Air Canada is highest; U.S., second; Japan, third; EEC, fourth; and USSR, last. The U.S., EEC, and USSR are the prime movers of traffic.

Traffic growth.- An illustration of the world's traffic growth in terms of revenue passenger miles is presented in figure 3 (ref. 9). Actual statistics for the years 1968 through 1974 are shown, as are predictions for the total International Civil Aviation Organization (ICAO) members. The ICAO curve is cumulative and the rest are absolute. "Other" ICAO member data are not presented in the interest of clarity. The insert table provides both the actual compound growth rates, for 1968-1974, and the projected 1975-1986 (low and high) estimated growth rates. These projections seem to agree with the generally accepted opinion that the airline industry is approaching maturity (i.e., growing only a little faster than the economy as a whole). An up-to-date analysis of future aircraft needs is contained in reference 10.

The estimated size of the market from 1976-1986 is also presented in figure 3. These simple estimates were derived from published market values in 1974 (ref. 11) and assumed that the future fleet mix would be approximately the same as in 1974.

The total market for the 1976-1986 time period is estimated to be from \$80- to \$100-billion (USSR included). If the USSR market is not available to the free-world industry, the market is still estimated to be between \$65- to \$80-billion. The largest share of the market will be in the U.S. (from \$27- to \$33-billion), with the EEC next highest (\$20- to \$24-billion). Thus, future markets are large and worth striving to attain.

Aeronautical Technology Comparisons

In comparing the status of the competitors in prime aeronautical technical disciplines such as aerodynamics, propulsion, structures and materials, and avionics, an attempt has been made to utilize meaningful quantitative relationships. These relationships are not an absolute measure of technology status, since individual disciplines are compromised by the many trades necessary in any aircraft design.

Aerodynamics.- A comparison of subsonic aerodynamic efficiency, as illustrated by lift-to-drag (L/D) ratio and Mach number (M) times L/D (M L/D), for representative U.S., EEC, and USSR transport aircraft is presented in figure 4. U.S. aircraft considered include: the Boeing 707-320C, 727-200, 737-100, and 747-100. EEC aircraft include the Airbus Industries A-300-B2; British Aircraft Corporation BAC-111-475; Hawker-Siddeley Trident Super 3B; and Vereinigte Flugtechnische Werke-Fokker FWF-614. USSR aircraft include the: Tupolev TU-134A and TU-154; and the Iluyshin IL-62 and IL-86.

Inasmuch as neither published performance data nor the necessary detailed geometric data (required to conduct a rigorous analysis) were available for the foreign aircraft, a simplified method was employed to estimate aerodynamic efficiency. The procedure consisted of utilizing published (Jane's All-the-World Aircraft) cruise speed, range, payload, fuel load, reserve fuel, and cruise specific fuel consumption data to derive the lift-to-drag ratios. The method was checked against more accurate data (ref. 12) and the results agreed within five percent.

The L/D of a modern airplane is selected on the basis of overall performance and economic trades, and is therefore not a completely reliable indicator of aerodynamic technology. Indeed, some of the more recent airplanes actually have lower L/D's than the early Boeing 707 and Douglas DC-8 airplanes. A better indicator is the comparison of airplane L/D with the ideal L/D obtained by considering only skin friction and induced drag. Ideal L/D depends principally on the ratio of wing span, (b), to the square root of configuration wetted area, ($\sqrt{S_{\text{wet}}}$). The ideal lift-to-drag ratio appropriate to the aircraft under consideration (for cruise altitude above 36,000 feet and Mach number from 0.7 to 0.85) is also presented in figure 4.

L/D comparisons indicate that the data correlates in a band represented by $13.7 (\frac{b}{\sqrt{S_{\text{wet}}}})^{\pm 8\%}$. U.S. aircraft are generally on the mid-to-high side of the correlation and vary from 71-to-79 percent of the ideal L/D values. The EEC aircraft (69-to-77 percent of ideal L/D) and USSR aircraft (67-to-76 percent of ideal L/D) are located on the mid-to-low side of the correlation.

A partial explanation of these results is provided by the plot of M(L/D) versus design range and a study of the aircraft wing loading characteristics. In general, the U.S. aircraft have higher design ranges, higher wing loadings, and higher differences in initial and final wing loadings and are therefore less compromised for the off-design takeoff and landing conditions than are the short-to-medium range EEC and USSR aircraft. The reasons for the lower than expected efficiency of the USSR long-range aircraft are not fully understood although it is presumed to be associated with the four aft mounted engine design which probably causes balance problems and trim-drag penalties.

Although the U.S. aircraft are indicated to have somewhat higher efficiency levels, differences in design approach offers a possible explanation for the aerodynamic differences since compromise for short, unprepared or rough fields, extreme cold weather operation, and centralized maintenance facilities could be responsible. These conditions suggest that the aerodynamic efficiency levels are on a par worldwide.

Engines.- A comparison of engine technology is presented in figure 5 (refs. 13, 14). Takeoff specific fuel consumption (SFC) and maximum static engine thrust-to-weight ratios are plotted as a function of engine introduction date. Levels of performance for the U.S. and EEC are assessed to be essentially the same and are shown as the shaded bands.

With regard to thrust-to-weight ratio, the USSR also has a comparable level of technology. For SFC, the USSR is assessed to be 2 to 4 years behind the U.S. and EEC - primarily because they do not, as yet, utilize the same high level of turbine-inlet temperature. This could be either a deliberate design philosophy to minimize reliability and maintenance problems, and/or a result of problems with metallics or cooling techniques. In any event, the comparison shows a closer parity than presented in previous studies (ref. 14) and indicates that the USSR is closing the gap in propulsion technology.

The USSR now has a high bypass ratio (5:32) engine in the 14,000-pound thrust class (ref. 15) that is being used in the YAK-42 short-haul aircraft. There is no indication that the USSR has as yet developed a high bypass ratio - high thrust engine (\approx 50,000 pound). There are indications that the USSR is negotiating with Rolls-Royce for RB-211 high bypass ratio - high thrust engines.

Reports from U.S. airlines utilizing both U.S. and Rolls-Royce engines indicate that the RB-211 has a superior capacity to retain a given level of specific fuel consumption and also shows rapidly improving reliability. A recent article (ref. 16) states that a new Rolls-Royce engine (RB-401) has an advanced combustion chamber design which reduces emission levels to 1979 standards (the first such claim). Also, both the EEC and USSR have engines to power their SST's, whereas the U.S. has no comparable engine.

Structures and materials.- A comparison of structural performance is presented in figure 6 (ref. 17). The gross measure of structural efficiency utilized is structural-weight-to-aircraft-surface-wetted area as a function of aircraft weight. The U.S. and EEC aircraft are shown as open symbols and the USSR aircraft are represented by solid symbols. The line fairings represent least-square curve fits to the individual aircraft data.

For takeoff gross weights under 200,000 pounds, free-world aircraft are considerably lighter than USSR aircraft. This is partly the result of a USSR design approach which configures aircraft for dual military/civil roles, and for austere terminal characteristics. At the higher gross weights, the pronounced convergence of the data indicate a nearly equal technology level.

A qualitative assessment of other structural areas is presented in figure 7. Regarding the mechanics of behavior of composites, all competitors are assessed to be on a par. With regard to composite applications, the U.S. is considered

to lead as a result of extensive DOD and NASA programs; the EEC lags because of funding limitations, Japan lags, and the USSR status is unknown.

In fatigue phenomena, the U.S. is thought to be ahead in experience and in application to long-life aircraft, although all parties are believed to possess the same basic level of understanding. With regard to fracture mechanics, the U.S. is estimated to be advanced, the EEC and Japan to be at a level sufficient to meet U.S. certification requirements, and the USSR known to have eminent analysts (applications of their work are largely unknown).

In polymers, the U.S. and EEC appear on par and the USSR appears to lag. In adhesive bonding, the U.S. does use this (i.e. L-1011 skin) but manufacturers generally prefer extrusions to reduce cost; the EEC, particularly the Netherlands, has made extensive use of adhesive bonding in the F-27 and F-28 aircraft; there is some indication that the USSR is using this technology but the extent is not known.

In production manufacturing, the U.S. leads in automation, the EEC is beginning serious automation, the Japanese industry is largely untried in transport aircraft, and the USSR is seeking to buy ready-made western world capability.

In large press development, which could lead to major breakthroughs in manufacturing processes, the USSR leads with machines of 75,000 metric-ton capability. With this press, the USSR has produced much larger forgings than have previously been demonstrated. The French have bought a 65,000 metric-ton press from the USSR. In this important area, the U.S. is assessed to lag since the largest press known is 45,000 metric-tons; substitute manufacturing techniques include diffusion bonding and thin sheet usage.

Avionics.- A qualitative assessment of the status in some of the avionics technology areas is presented in figure 8.

The U.S. is considered to lead in air traffic control systems (refs. 4, 18) because the U.S. has a nationally unified system developed by the Federal Aviation Administration. The EEC has no effective unified system (because of individual national views) although several of the EEC members produce excellent systems. The USSR and Japan have no known advanced system. The Japanese have purchased U.S. systems. The USSR was denied permission to purchase U.S. systems because the technology could be utilized to increase military capability.

With regard to navigation systems, the U.S. is assessed to lead because of its advanced satellite, inertial, gyro, and VOR/DME area navigation capability. The EEC is also known to have a superior area navigation capability. The USSR is not known to have navigation satellite capability as yet, although there is intensive activity on inertial systems.

In terminal area research, the U.S. is considered to lead as the NASA/FAA/industry cooperative Terminal Configured Vehicle program (ref. 19) is assessed to be the most advanced, both in scope of activity and in flight demonstration equipment. The EEC is known to have advanced research both

underway (UK) and contemplated (France). The status of USSR and Japanese work is not known.

The USSR prefers adoption of a scanning-beam microwave landing system (MLS) similar to the MLS proposal which the U.S. made to the International Civil Aviation Organization (ref. 20).

Active controls.- Figure 9 presents a qualitative assessment of the status (ref. 21-24) of some active control technology areas.

The U.S. is considered to lead in basic research with much work underway; the EEC is competitive and the USSR is thought to be competitive. The United Kingdom is strong in fly-by-wire hardware (i.e. - development and production of digital flight control system for the Boeing YC-14) and France and West Germany have major wind tunnel efforts going on (models used are generally not as sophisticated as are U.S. models). The USSR closely monitors the results of Western work and has its own studies of relaxed static stability and other areas ongoing. Presently, Japan has little interest in this work and is thought to have only minor work underway.

The U.S. leads in flight testing active controls (B-52, B-58, XB-70, C-5A, F-4, F-8, YF-16, F-111, F-104, L-1011, and 747) and is pursuing relaxed static stability, gust-load alleviation, yaw damping, and fly-by-wire technology (ref. 25). The EEC has a smaller overall effort but has applied a degree of relaxed stability to the Concorde, is working fly-by-wire (W. Germany: F-104G; U.K.: Hunter; Sweden: Viggen) and has plans for flutter tests. The USSR is known to have made flight tests of active controls and is thought to be in a competitive position with the U.S. Japan has not made any flight tests and is without a strong incentive to do so without a major aircraft development program ongoing.

In applications, the U.S. has placed an active load distribution control system on the C-5A, and the 747 and L-1011 have yaw dampers. The EEC has used an autostabilizer on Concorde for relaxed static stability and to move fuel around. Russian applications are unknown.

Overall, the U.S. is assessed to be somewhat ahead in active controls because of strong past (military, civil, and space program spinoffs) and current efforts. The EEC and USSR are assessed to be competitive with the U.S. and possess the ability for applying the technology to future aircraft, and Japan is well behind the U.S.

1976 Competitive Situation

A summary of the aerospace industry competitive status (in 1976) is presented in figure 10.

In discipline technology, the U.S. is assessed to be predominant; the EEC is estimated to be somewhat lagging in a few areas. The USSR is assessed to be

somewhat behind in structures, although this judgment must be tempered by uncertainties as to whether USSR aircraft reflect a deliberate design philosophy slanted towards civil/military commonality and rough field capability. The USSR is assessed to be weak in other areas although there are indications that these weaknesses are recognized and that efforts are being made to correct them. The Japanese are currently assessed to have little commercial aircraft development capability and will require approximately 10-15 years of effort to develop such capability. The U.S. is relatively strong in the development of major aircraft systems and often sells this equipment to EEC aircraft manufacturers. Another U.S. strong point is the close coordination which exists between airline customers and airframe/engine manufacturers during the development and design of a new aircraft.

In the length of production run, the U.S. and USSR are assessed to be strong and the EEC is assessed to be weak. The U.S. manufacturing position is fundamentally dependent on the traffic moved by U.S. airlines. The Japanese capability for building complete large aircraft is essentially nonexistent, although they have some experience with the YS-11 and have been building wing flaps for the B-747 SP (ref. 26).

With regard to business aspects, the U.S. is currently assessed to be weak with respect to both the USSR and the EEC because of the poor financial health of the U.S. industry which is suffering from lack of adequate profit, available capital, and a national plan to effect recovery. Foreign firms also have government capital available to them when needed, whereas U.S. firms must rely on their own resources.

In marketing, the U.S. has demonstrated outstanding strength in post-sales support including collaboration on operational problems as well as prompt spare parts availability, whereas the other participants have not performed as well.

Typical foreign government ownership of airlines and manufacturers puts great pressure (and sometimes a directed procurement policy) on airlines to buy their own national products. At times, however, EEC airlines have bought competing U.S. aircraft rather than purchase an inferior product manufactured locally.

Existing Competitive Aircraft and New Projects

A comparison of existing and prototype transport aircraft projects for various market categories is presented in figure 11 (also see table I). As a further aid in identifying foreign aircraft, photographs and pertinent characteristics are presented in figure A-1 through A-14 of the Appendix. Both the EEC and USSR have projects in nearly all of the range-payload categories traditionally dominated by the U.S. It is important to note that both the EEC and USSR have SST's (figures A-1 and A-2) in scheduled service, while the U.S. does not.

The EEC is considering a number of derivative versions of an A-300 aircraft (figures 12, A-3). A long-range version, designated the A-300 B-11, is being carefully studied by airlines such as Aero-Lingus (ref. 27) and Lufthansa.

The USSR announced (ref. 28) that it has a prototype medium-range wide-body transport, the Iluyshin IL-86 (figure A-4), being flight tested and a second prototype which will be in tests late in 1976. The USSR has historically taken an excessive amount of time to place a new aircraft in service (from the first flight). The YAKOLEV YAK-42 (figure A-11), a larger and improved aircraft similar to the YAK-40 (figure A-14) is apparently intended to be a short-range aircraft in the DC-9 and B-737 class. Estimates have been made that Aeroflot anticipates a need for about 2,000 YAK 42's (ref. 29). It utilizes the first known USSR high bypass ratio (5:32) engine. YAK-42 passenger accommodations are similar to a Western world airplane.

An estimated schedule of other potential aircraft project introduction dates is presented in figure 12. The solid symbols denote recent introductions and the open symbols denote planned introductions. Of interest is the large number of recently introduced EEC and USSR aircraft (1975-1977) and the number of planned EEC introductions in the 1978-1979 time period. Although some derivatives (i.e. 7N7 - a derivative of existing narrow-body jets, DC-10-X models) of existing U.S. aircraft are possible, advanced projects such as the Boeing 7X7, the Douglas DC-X-200, and the Lockheed Reduced Energy RE-1011 are not expected to be introduced until the early 1980's, or later.

With regard to second generation or advanced SST's, there is much doubt that a single competitor can afford the high expected development cost (\$4B+) and it is possible that an international consortium between the U.S. and EEC will result. It is estimated that the earliest introduction date for an advanced SST is in the latter-half of the 1980's.

Problem Areas

Multinational ventures.- The U.S. aviation industry is currently experiencing an extremely difficult time in acquiring the financing needed to undertake new aircraft developments. As a result, U.S. firms are already undertaking cooperative ventures with foreign firms and planning even more extensive projects. Some examples are listed in figure 13. Inasmuch as foreign companies are largely government owned and financed, U.S. companies are essentially dealing with foreign governments. While U.S. firms can team with foreign communities, they are restricted from doing likewise with other U.S. firms because of antitrust laws. Foreign competitors also either have (USSR) or are beginning (EEC) unified aviation plans and coordinated policies (ref. 30). The U.S. has no such policy to guide the industry, although one serious attempt was made to formulate such a plan (see ref. 31).

A prime example of a multinational aeronautical project is the JT10-D effort illustrated in figure 13 (ref. 32). The various companies involved are Pratt and Whitney (54 percent share of development cost), Rolls-Royce (34 percent), Motor Turbine Union (9 percent), and Fiat (2 percent). Other ongoing activities include the CFM-56, General Electric and SNECMA (France); the 7X7, Boeing

and Aeritalia (Italy); DC-10 derivative, Douglas and UK; and the A-300, Air-bus Industries and General Electric. Projects now under discussion are: 7X7, Boeing and Japan; DC-9-QST, Boeing and Japan; DCX-200, Douglas and France; A-300B (advanced), Boeing and Airbus Industries; and the 7N7, Boeing and France.

An important reason why foreign countries can successfully press for a share of new aircraft production is because the relative importance of U.S. airlines is shrinking. As indicated in figure 14, the U.S. share of the revenue passenger miles has decreased from approximately 70 percent in 1960 to about 45 percent in 1975. Large scale joint production agreements may reduce U.S. aerospace employment, which has already decreased from about 1-1/2 million people in 1968 to about 921,000 people in 1975 (fig. 15). The significant question is whether U.S. employment is maximized by projects which share markets and jobs with foreign nations or by continued U.S. dominance in transport markets (which implies that the U.S. insure that American firms are able to develop new aircraft independent of foreign governments).

From the U.S. viewpoint, multinational ventures provide some advantages in that large development costs and risks are reduced, and guaranteed access to the foreign partner's market is obtained. Disadvantages foreseen are the creation of future competitors through transfer of U.S. technology (this is particularly significant when foreign research and development efforts grow faster than U.S. effort) and dilution of the employment and sales base.

Another problem area of concern to U.S. airframe and engine companies - and to NASA by virtue of its charter role in maintaining an advanced U.S. aeronautics research and technology base - is the size of the NASA aeronautics funding level (as contrasted to what the industry believes is needed), and the importance of the U.S. advanced technology base to maintaining a large volume of aerospace exports.

Figure 16 presents the total NASA aeronautics funding level, the research and technology (R&T) base (in both current and 1976 constant dollars), and overall NASA R&D funding for the period from 1967 to 1977. Aeronautics funding has shown a continued rise to over \$188 million in fiscal year 1977. Major airframe and engine manufacturers indicate that to maintain U.S. preeminence, an aeronautics funding level of approximately \$1 billion per year is required. A portion of this funding is needed to insure that effective industry research and design teams are kept together. Such an involvement has been underway for several years in the NASA Supersonic Cruise Aircraft Research (SCAR) program (ref. 33), at a relatively low level, and another such venture is evolving in the NASA/Industry Aircraft Energy Efficiency (ACEE) program (ref. 34).

Another point of interest is that the R&T funding share has decreased from over 80 percent in 1967 to approximately 50 percent in 1976. Basically, R&T funding is a long-term investment in ideas which have high payoff provided enough information is eventually gathered to reduce the risk of innovation to acceptable levels. The past funding trend has been helpful to near-term systems technology and experimental programs but of less help to long-term basic research.

Some military development programs also provide benefits to civil aviation. However, emergence of problems such as aircraft noise and much more expensive fuel mean that civil aviation applications of military technology are now much less frequent than was true in the past. This additional problem makes increased R&T funding even more important.

Additional Topics Needing Study

This work also identified a number of other areas needing study and analysis. A partial list follows:

- Long-term impact of multinational project development.
- European technology areas advanced by the development of the Concorde.
- Essential elements of a national aviation policy.
- Impact of continued U.S. civil market dominance on EEC behavior.

CONCLUSIONS

A study of competitive aspects of foreign civil aviation indicates the following conclusions:

1. The U.S. currently dominates the market for manufacture of commercial aircraft. It is questionable whether this will continue in the future.
2. Transport aircraft represent the largest share of the civil aviation market, both today and in the foreseeable future.
3. There is a large future market, estimated to be from \$80-\$100 billion from 1976-1986 (if the USSR is included), and from \$65-\$80 billion if the USSR market is inaccessible.
4. The primary competitors to the U.S. are the EEC in the near term and the USSR in the long term. Both of these competitors:
 - o are developing or acquiring advanced technology capabilities
 - o are planning future aircraft projects
 - o lead in supersonic transport experience
 - o have made major technological breakthroughs in the past and probably will do so in the future
 - o probably cannot challenge the U.S. across-the-board but can take a part of each market away.
5. Under present policies, multinational projects will proliferate in the future because there are advantages for both U.S. firms and for foreign partners. U.S. companies need development money, risk-sharing, and foreign market access. Foreign partners need U.S. technology and business know-how. Such arrangements have long-term risk to the U.S. in that they create future competitors, transfer hard-earned U.S. technology, and dilute U.S. sales and employment levels. U.S. companies now deal with foreign governments and firms regularly but cannot effectively cooperate with each other.
6. Continued U.S. preeminence is dependent on superior products which will require larger budgets for both the necessary long-term research and technology work and near-term systems technology programs.

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TABLE 1. - COMMERCIAL JET AIRCRAFT ORDERS

USA ¹	EEC ¹		USSR ²		
	CARAVELLE	278	IL62	81	
BOEING 707/720	897	BAC 111	219	TU104	180+
BOEING 727	1195	TRIDENT	117	TU124	93
BOEING 747	283	Vc 10	47	TU134	209
BOEING 737	407	COMET	51	TU154	65
DC 8	556	MERCURE 100	10	YAK40 *	600
DC 9	802	CONCORDE	9		1228+
DC 10	240	AIRBUS A 300	23		
L 1011	150	F 28 *	95		
CONVAIR 880/990	83	VFW 614 *	10		
	<u>4613</u>				
	(512 AVE.)				
			859		
				(86 AVE.)	

¹DEC 1974

²MID 1974

*FEEDER AIRCRAFT

TABLE II. - RECENT AIRCRAFT ORDERS

<u>AIRPLANE</u>	<u>1974</u>	<u>1975</u>
B-747	29 (3)	20 (0)
B-737	47 (3)	35 (1)
B-727	95 (52)	50 (25)
B-707	17 (0)	9** (1)
 L-1011	 14 (0)	 0
DC-10	4 (0)	18 (1)
DC-9	47 (29)	20 (2)
* A-300	-6 (0)	16 (0)

* 32 ORDERS TO DATE PLUS 24 OPTIONS

** 6 ORDERS TO U.S. MILITARY
 () ORDERED BY U.S. AIRLINE

TABLE III. - AIRLINE COMPARISON - 1974

<u>% STATE OWNERSHIP</u>	<u>REVENUE PAX-MILES MILLIONS</u>	<u>PAX THOUSANDS</u>	<u>EMPLOYMENT</u>
USA SCHEDULED AIRLINES	0	162,917	207,449
AEROFLOT	100	67,500	88,000
BRITISH AIRWAYS	100	15,300	16,655
AIR FRANCE	98	10,500	7,593
LUFTHANSA	74	7,900	9,502
JAPAN AIR LINES	45	10,500	9,205
AIR CANADA	100	14,884	11,055
			20,500 EST

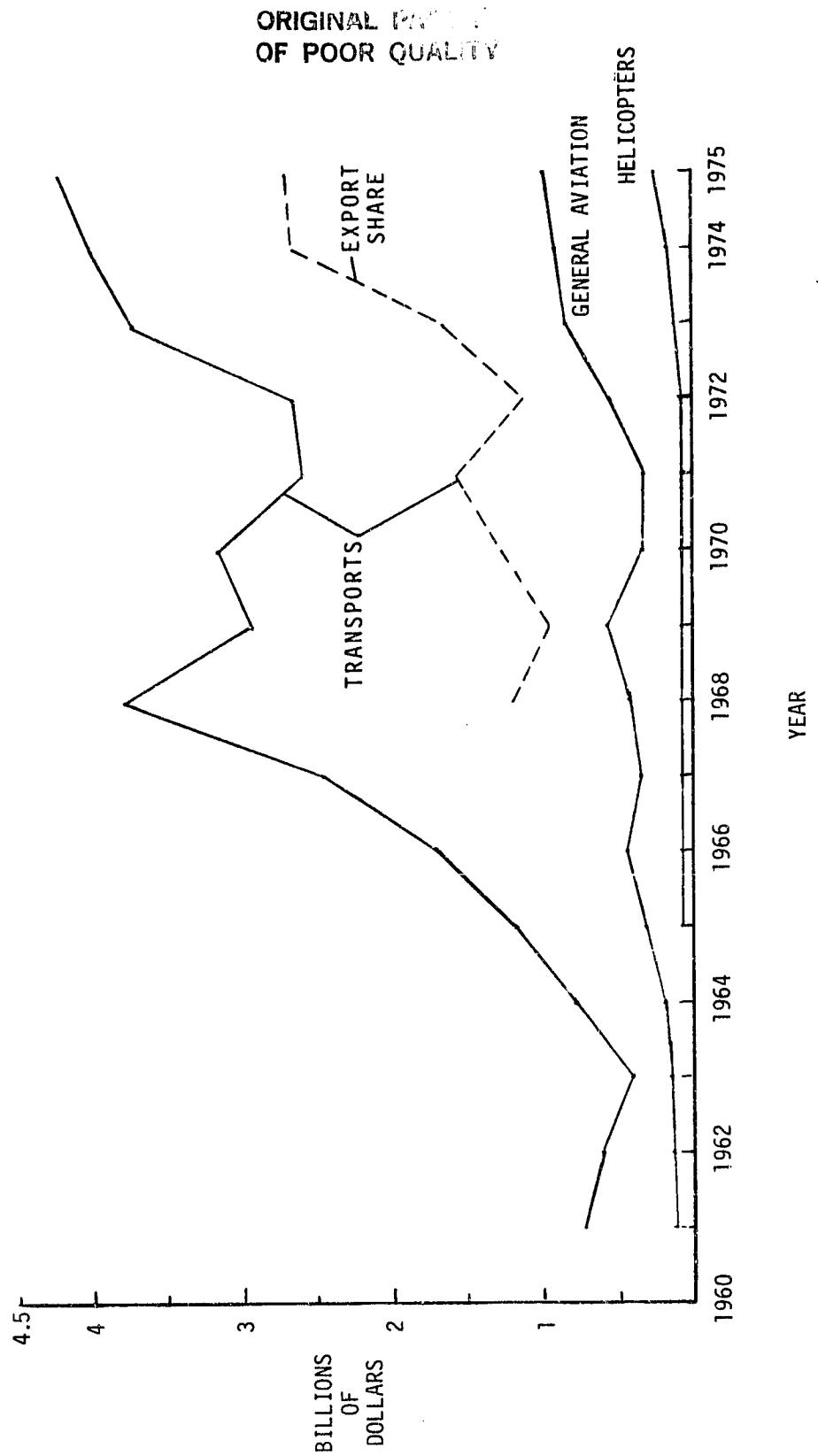


Figure 1. - U.S. commercial aircraft shipments
(then year dollars)

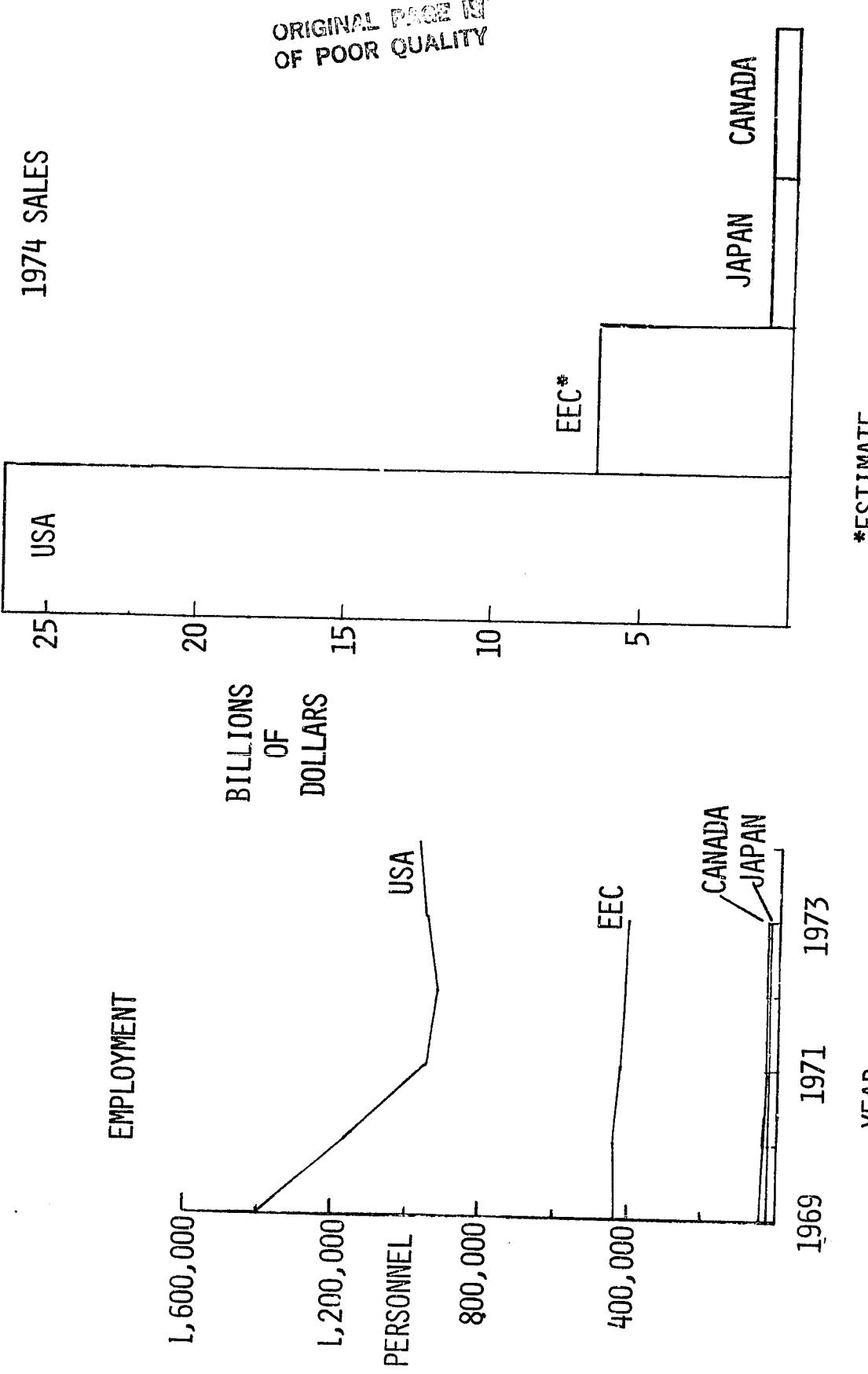


Figure 2. - Aerospace sales and employment -
military and civil

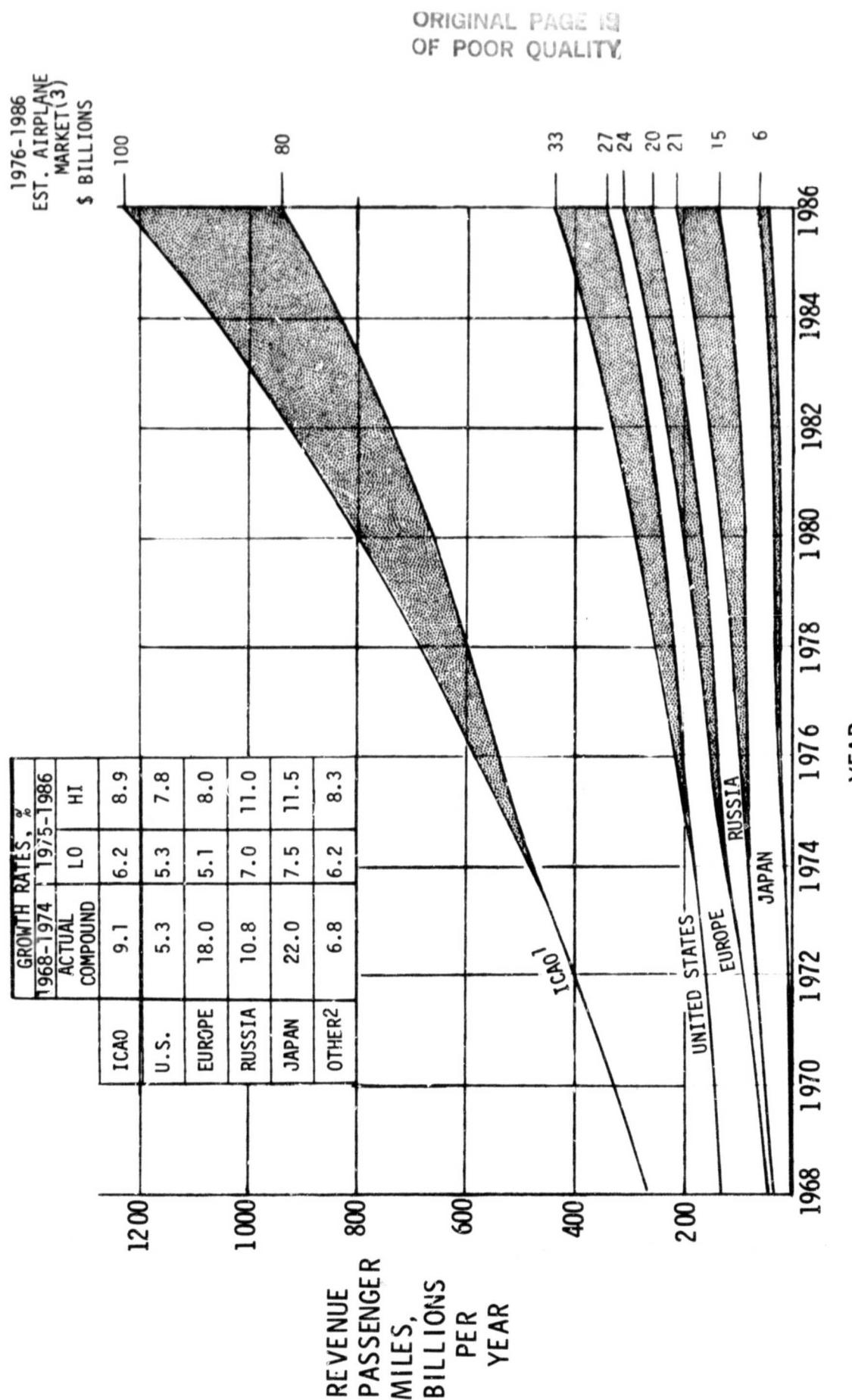


Figure 3. - World traffic growth

○ US
 □ EEC
 ▲ USSR

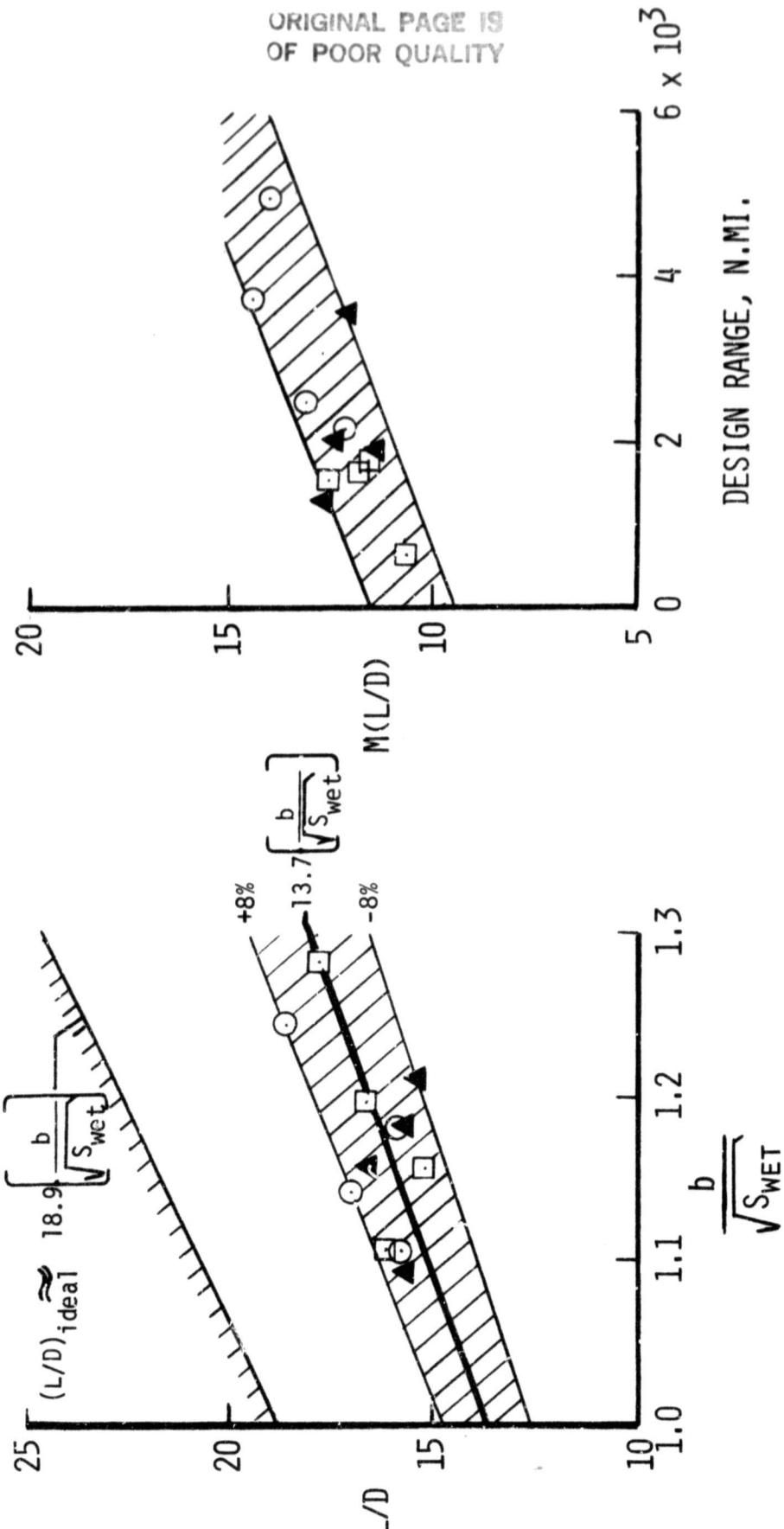


FIGURE 4.- AERODYNAMIC TECHNOLOGY COMPARISON

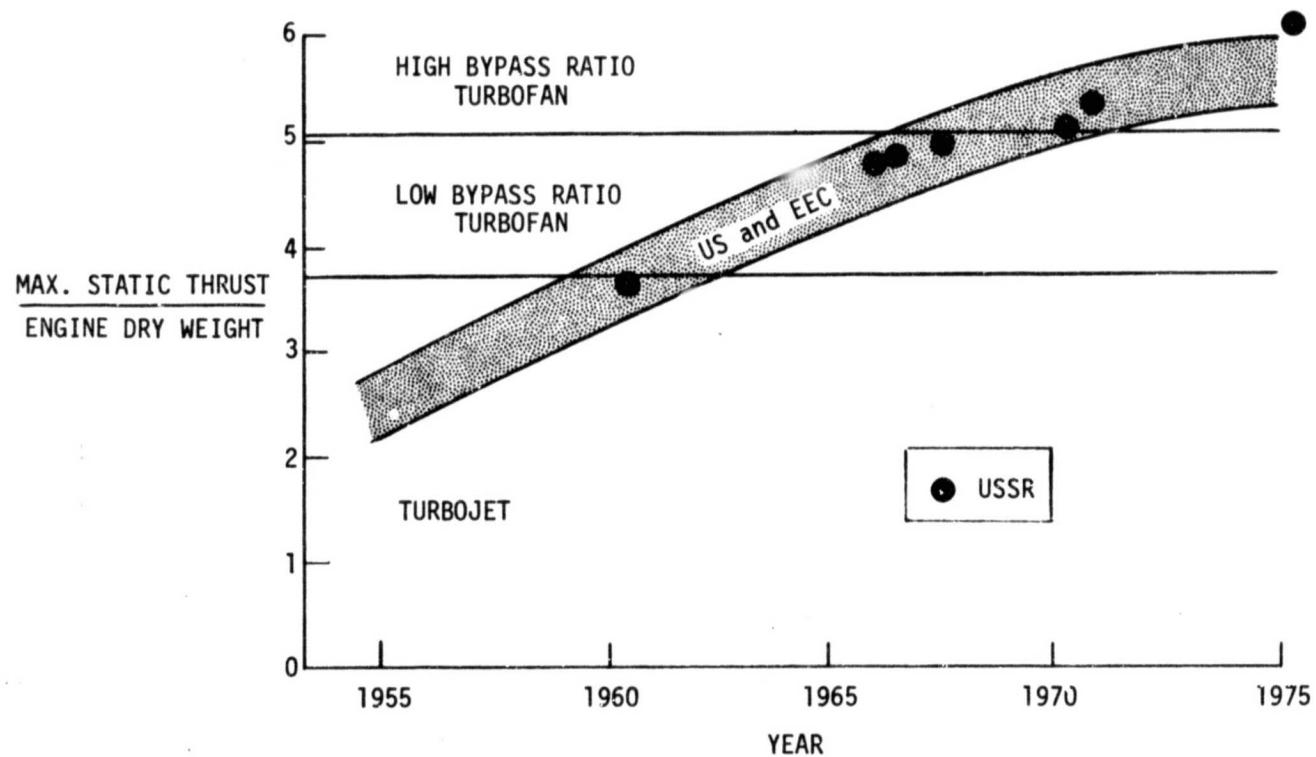
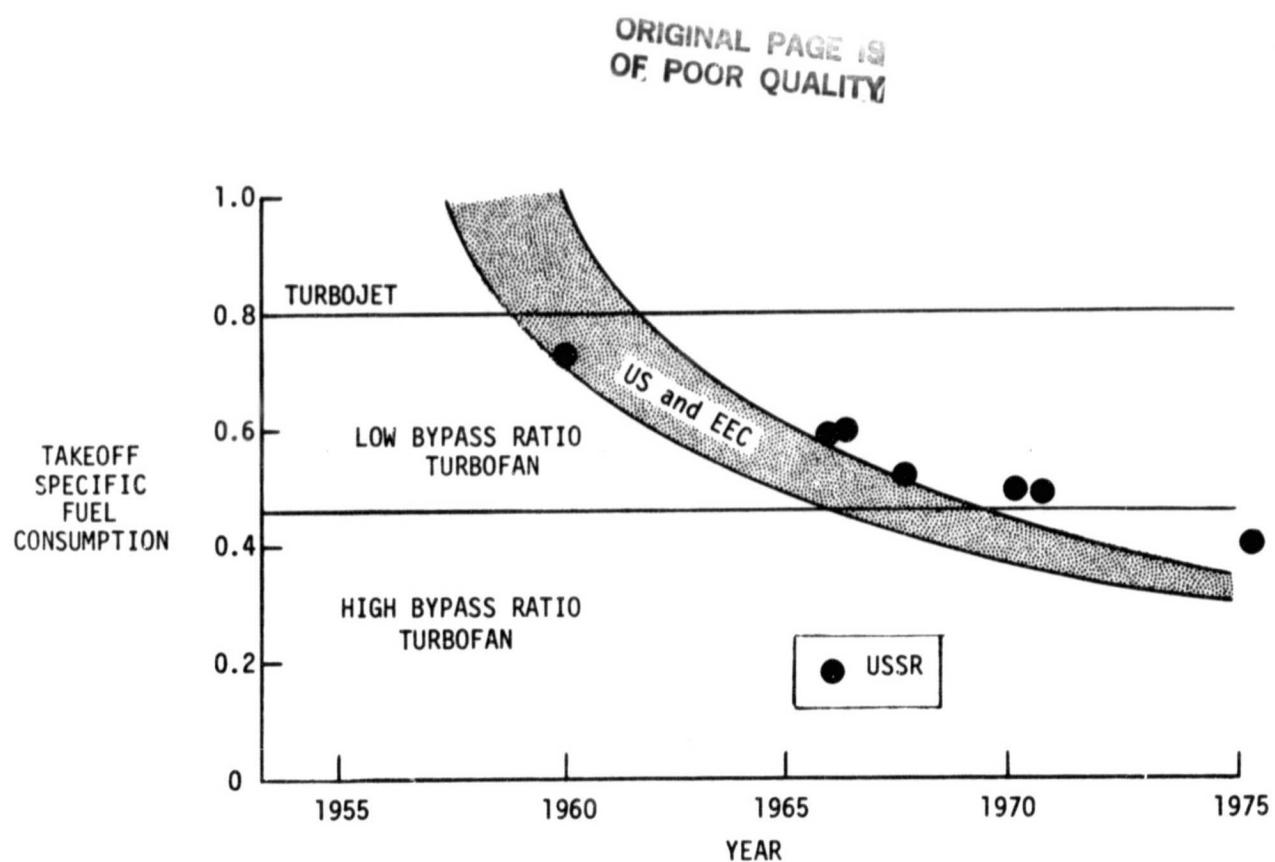


Figure 5. - Engine technology comparison

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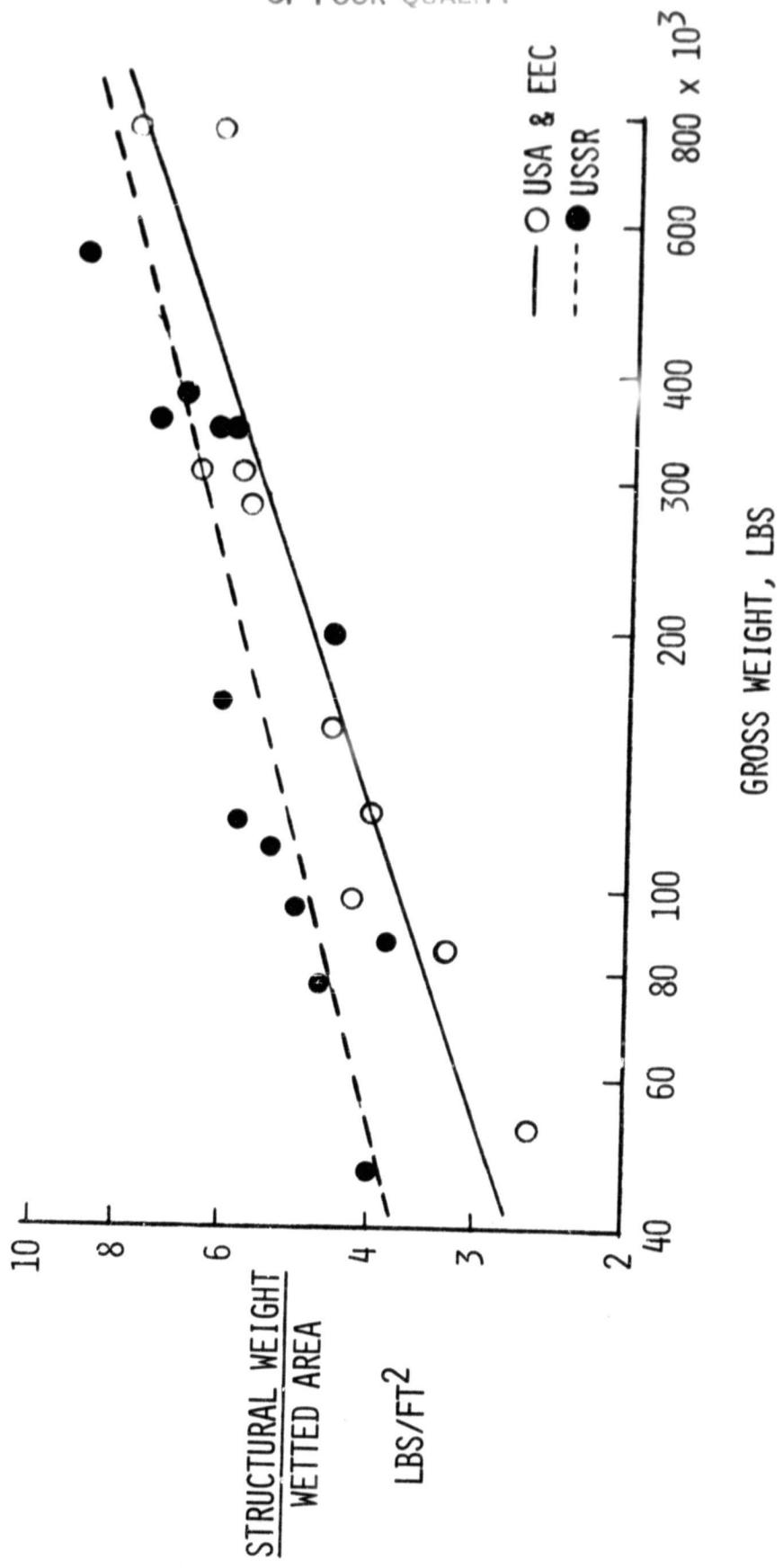


Figure 6. - Structural efficiency comparison

	US	EEC	JAPAN	USSR
COMPOSITES ● MECHANICS OF BEHAVIOR ● APPLICATIONS	PAR	PAR	PAR	PAR
LEADS: DOD, NASA ACEE AND R&T BASE	LAGS: FUNDING LIMITATIONS	LAGS (?)	UNKNOWN - LACK OF DATA	ORIGINAL OF POOR QUALITY
FATIGUE	TECHNOLOGY PAR, BUT MORE EXPERIENCED	PAR	PAR	LAGS (?)
FRACTURE	ADVANCED	AS REQUIRED TO MEET US/RTIFICATION STANDARDS	EMINENT ANALYSTS - APPLICATIONS UNKNOWN	WANTS TO BUY WESTERN CAPABILITY
MANUFACTURING	LEADS IN AUTOMATION	BEGINNING AUTOMATION	UNKNOWN	LAGS
POLYMERS	PAR	PAR	UNKNOWN	LAGS
ADHESIVE BONDING	L-1011 SKIN, PREFERENCES EXTRUSIONS TO REDUCE COST	EXTENSIVE USE: F-27, F-28	UNKNOWN	USING
LARGE PRESSES	LAGS: 45,000 M. TONS (USAF) LARGEST	FRANCE BOUGHT FROM USSR (65,000 M. TONS)	UNKNOWN	LEADS: 75,000 M. TONS - LARGER FORGINGS - RESEARCH

Figure 7. -Structures and materials assessment

CATEGORY	USA	EEC	USSR	JAPAN
AIR TRAFFIC CONTROL	<ul style="list-style-type: none"> ● UNIFIED SYSTEM <ul style="list-style-type: none"> -FLIGHT PLAN PROCESSING -RADAR DATA PROCESSING -INTERACTIVE CONTROL 	<ul style="list-style-type: none"> ● EUROCONTROL : <ul style="list-style-type: none"> NATIONALISM PREVENTS UNIFICATION ● ADV. CAPABILITY BY INDIVIDUAL MEMBERS <ul style="list-style-type: none"> -FRANCE -NETHERLANDS -SWEDEN 	<ul style="list-style-type: none"> ● NO KNOWN ADVANCED SYSTEM <ul style="list-style-type: none"> -DESIRED U.S. SYSTEM (DENIED) -BOUGHT SWEDEN (ATCAS) 	<ul style="list-style-type: none"> ● NO KNOWN ADVANCED SYSTEM <ul style="list-style-type: none"> BOUGHT USA TOKYO-OSSAKA
NAVIGATION	<ul style="list-style-type: none"> ● NAVSTAR-1984 (?) ● ADVANCED INERTIAL GYROS ● ADVANCED RNAV 	<ul style="list-style-type: none"> ● SUPERIOR RNAV (DECCA) 	<ul style="list-style-type: none"> ● NO KNOWN NAVIGATION SATELLITES ● INTENSIVE ANALYTICAL ACTIVITY ON INERTIAL SYSTEMS 	<ul style="list-style-type: none"> ● NOT COMPETITIVE
TERMINAL AREA RESEARCH	<ul style="list-style-type: none"> ● TCV-MOST ADVANCED PROGRAM-SCOPE AND EQUIPMENT 	<ul style="list-style-type: none"> ● UK - BAC-111 AUTOLAND RESEARCH ● FRANCE - HEADS UP DISPLAY 	<ul style="list-style-type: none"> ● NOT KNOWN ● CONTEMPLATING CARAVELLE TCV TYPE PROGRAM ● HEADS UP DISPLAY 	<ul style="list-style-type: none"> ● NOT KNOWN

Figure 8. - Avionics technology

CATEGORY	USA	EEC	USSR	JAPAN
BASIC RESEARCH	LEADS	COMPETITIVE MANY	COMPETITIVE - MANY - CLOSELY FOLLOWS WESTERN WORK - RELAXED STABILITY	LITTLE INTEREST MINOR EFFORT NONE KNOWN
● ANALYTIC	LEADS			
● SIMULATIONS	MANY - INCLUDING COMPLETE FLIGHT HARDWARE SYSTEMS	UK: FLY-BY-WIRE HARDWARE	YES	NONE KNOWN
● WIND TUNNEL TESTS	MANY: MODELS -WELL INSTRUMENTED -GENERAL, SPECIFIC	FRANCE & W. GERMANY -FLUTTER SUPPRESSION -AEROELASTIC	YES	NONE KNOWN
FLIGHT TESTS	LEADS	SOME CONCORDE	YES	NONE
● TRANSPORTS	MAJOR MILITARY/ CIVIL EFFORT	GUST LOAD ALLEVIATION FLUTTER TEST PLANS		
● FIGHTERS	MANY	UK, W. GERMANY, SWEDEN DOING		
● FLY-BY-WIRE	NASA, MILITARY			
APPLICATIONS	-ACTIVE MANEUVER LOAD CONTROL (C-5A)	UK: ADVANCED FIGHTERS CONCORDE: RELAXED STATIC STABILITY THRU AUTOSTABILIZER SWEDEN: VIGGEN DIGITAL FLIGHT CONTROL SYSTEM (747, L-1011)	UNKNOWN	NONE

Figure 9. - Active controls technology

	<u>USA</u>	<u>EEC</u>	<u>USSR</u>
TECHNOLOGY			
- AERODYNAMICS	S	S	S
- STRUCTURES	S	S	S-
- PROPULSION	S	S	W
- AVIONICS	S	S	W
- ACTIVE CONTROLS	S	S	S-
- SYSTEMS	S	S	W
- DESIGN COORDINATION	S	S	W
- MANUFACTURING	S	S	S-
PRODUCTION RUN			
	S	W	S
BUSINESS			
- FINANCING AND SALES TERMS	W	S-	S
- MARKETING	S	S-	W
POST-SALES SUPPORT			
	S	W	W

S = STRONG

W = WEAK

Figure 10. - Assessment of competitive situation, 1976.

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EXISTING
 PROTOTYPE

CATEGORY	USA	EEC	USSR
SST		CONCORDE SST	TU-144 SST
WIDE BODY LONG-RANGE	B747 DC-10-30/40		
WIDE BODY MEDIUM RANGE	DC-10-10 L-1011	A-300B	IL-86
STANDARD LONG RANGE	B707		IL-62
STANDARD MEDIUM RANGE	B727	TRIDENT 3 MERCURE	TU-154
STANDARD SHORT RANGE	DC-9 B737	BAC-111 F-28	TU-134A YAK-42
FEEDER		VFW-614	YAK-40

Figure 11. - Competing aircraft

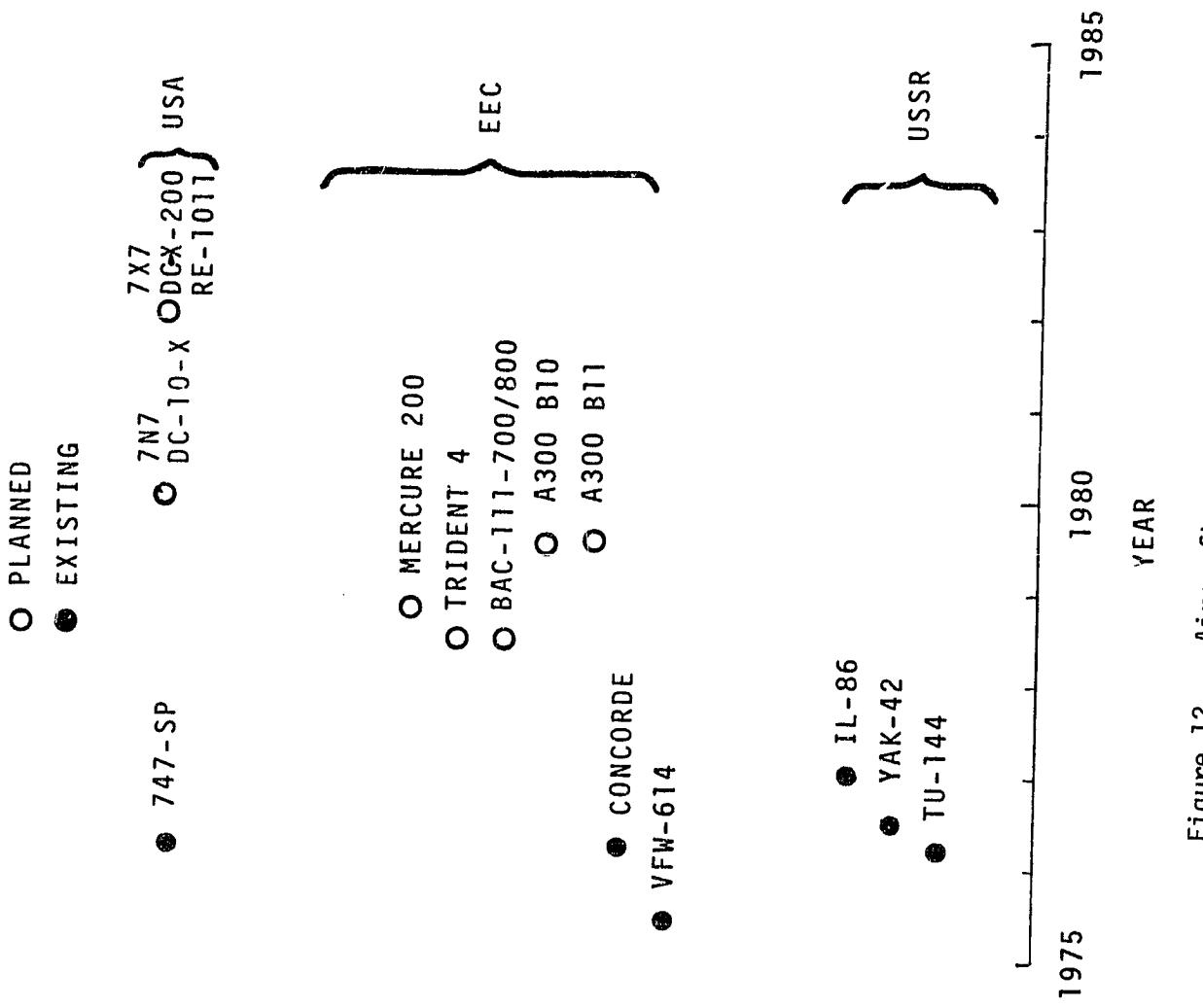


Figure 12. - Aircraft project introduction

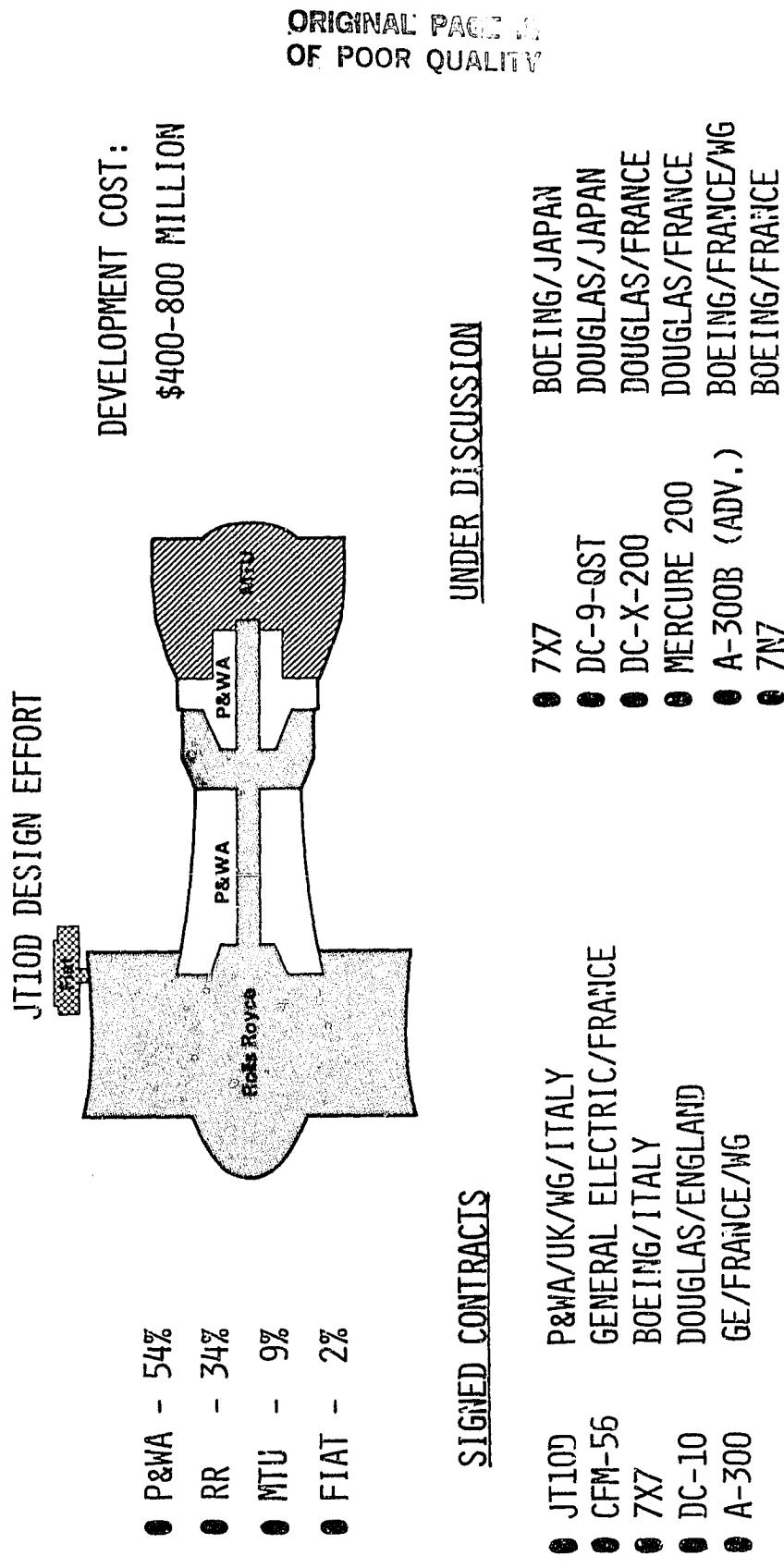


Figure 13. - Multi-national aeronautical projects

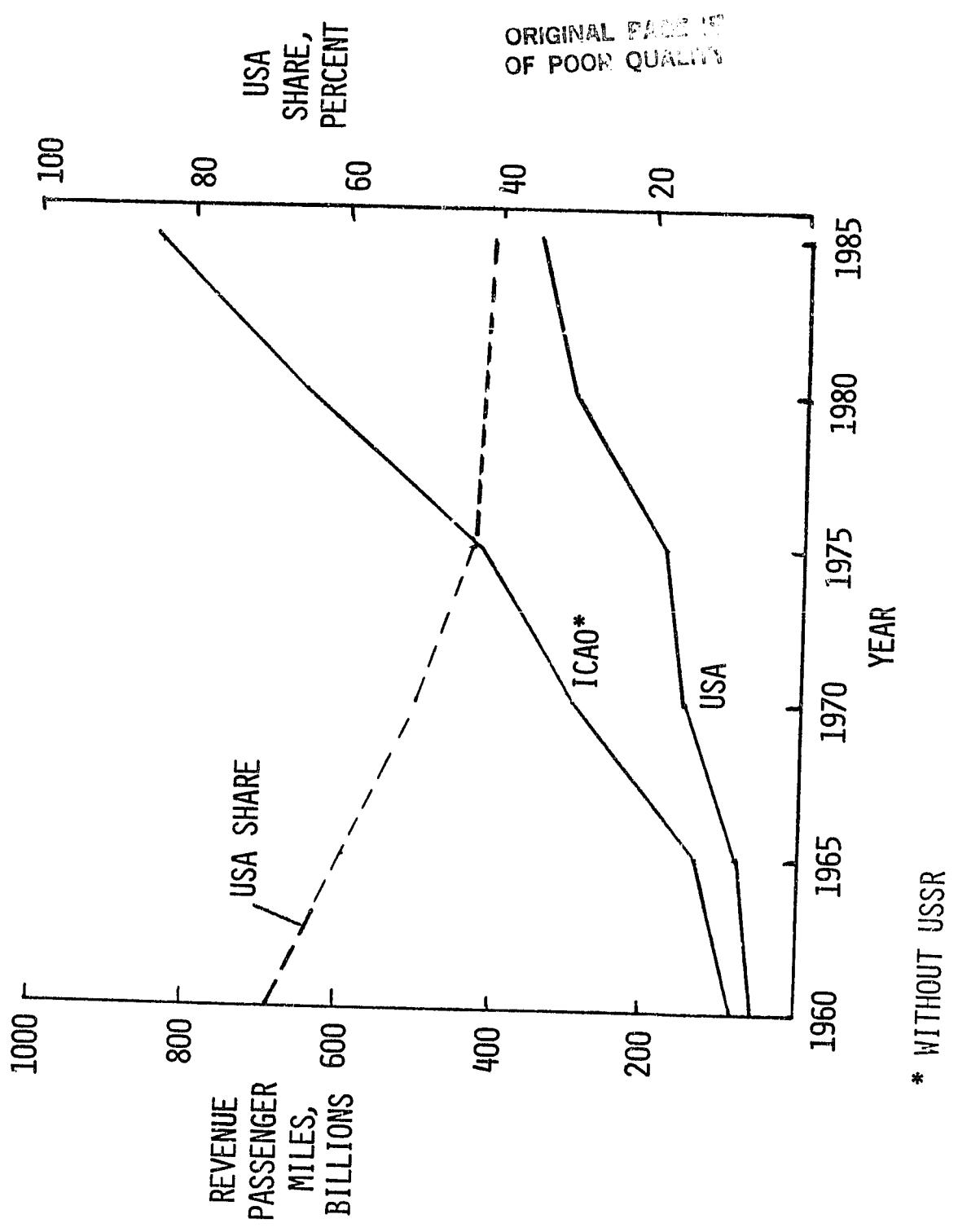


Figure 14. - World traffic projections

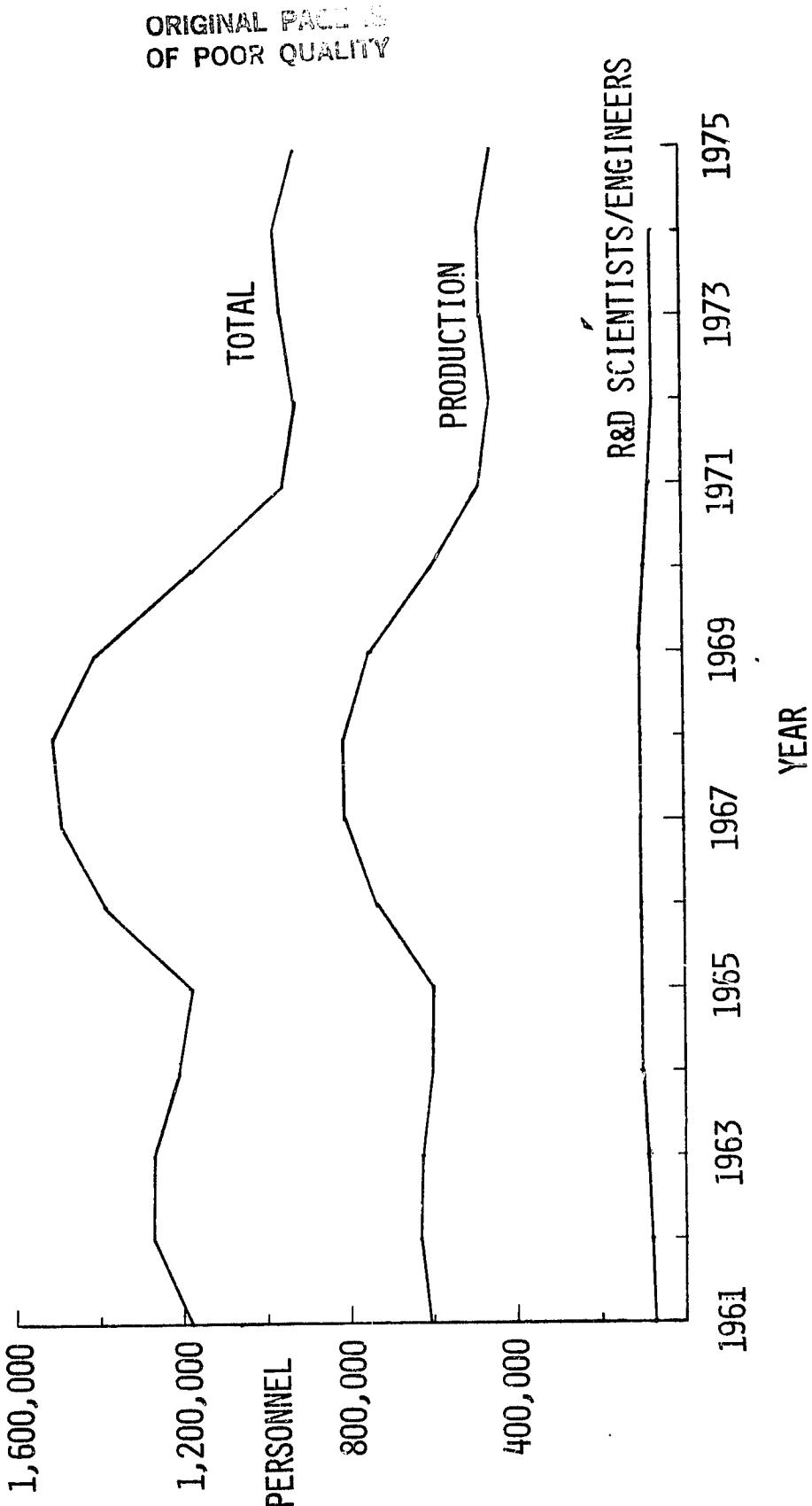


Figure 15. - U.S. aerospace employment

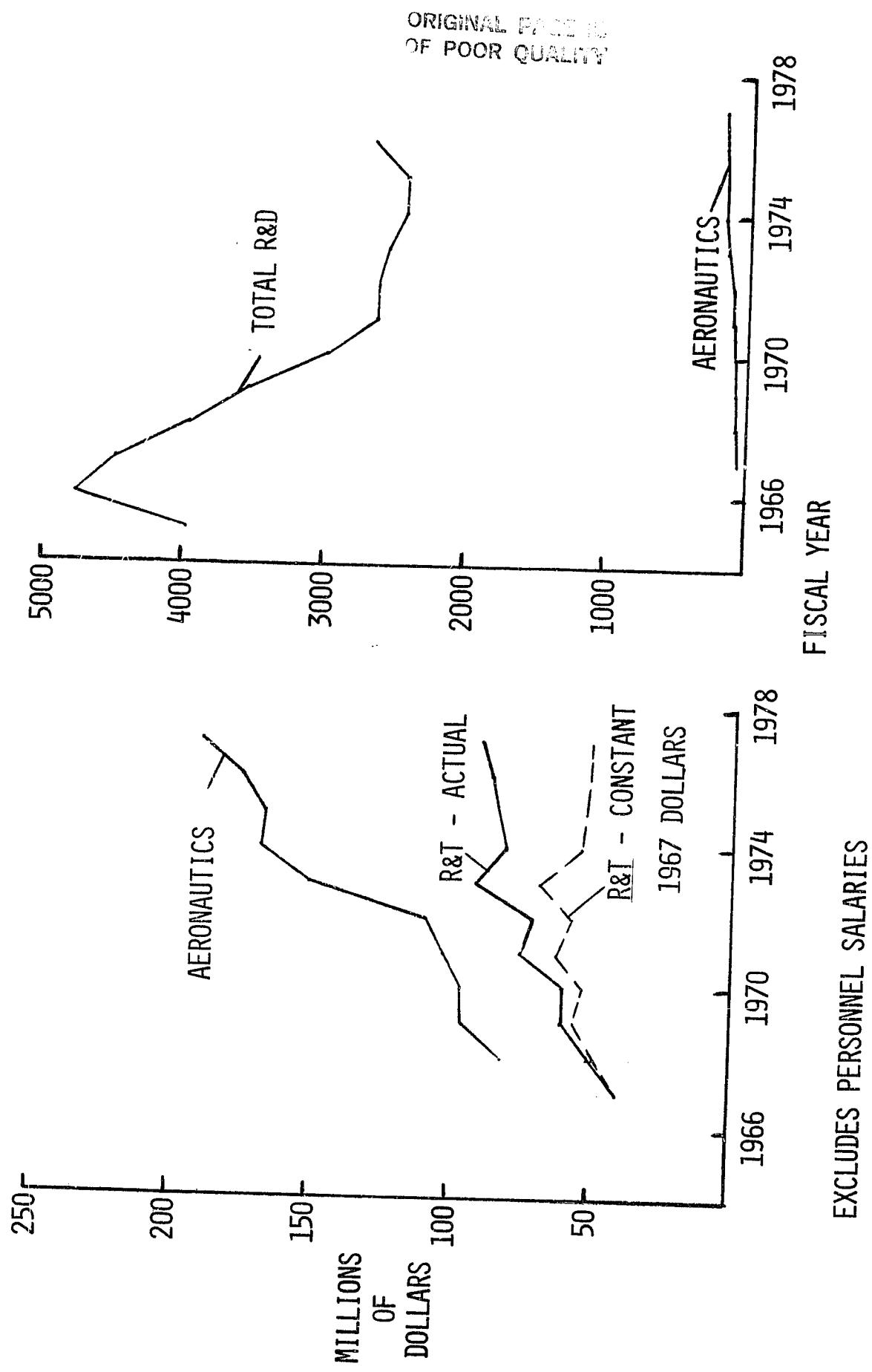


Figure 16. - NASA aeronautics funding

APPENDIX A

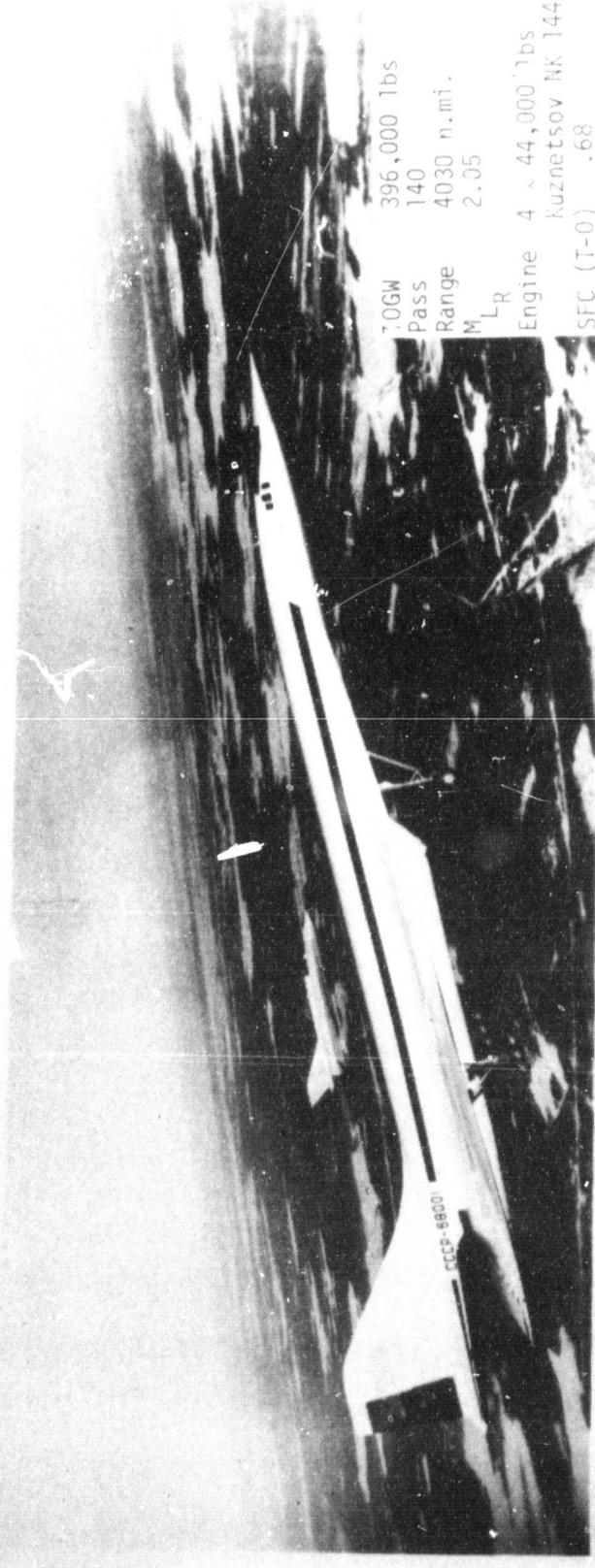
PHOTOGRAPHS OF FOREIGN TRANSPORT AIRCRAFT



Figure A-1. - Aerospatiale - British Aircraft Corporation Concorde SST.

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TU-144 AND SUB-SCALE MIG-21 DEMONSTRATOR



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Figure A-2. - Tupolev TU-144 SSI and MIG-21 demonstrator aircraft.

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A300

	B2	B4	B9	B10	B11
TOWW (lbs)	313,055	330,700	320,000	300,000	390,000
Pass	269	269	336	214	197
RANGE n.mi.	1510	2200	1200	2200	6000
M_{L_R}	.8	.8	.8	.8	.8
Engine	2 x 51,000 lb CF6-50C	CF6-50C	2 x 53,400 lb CF6-50L	2 x 45,000 lb CF6-45	4 x 22,000 lb CFM-56
SFC (T-O)	.394	.394	.398		



Figure A-3. - Airbus Industries A300 B4 aircraft.

TOGW 415,000 lbs
Pass 350
Range 2020 n.mi.
 M_{L_R} .85
Engine 4 x 26,455 lb
Soioviev D-30KP
SFC (T-0) .62

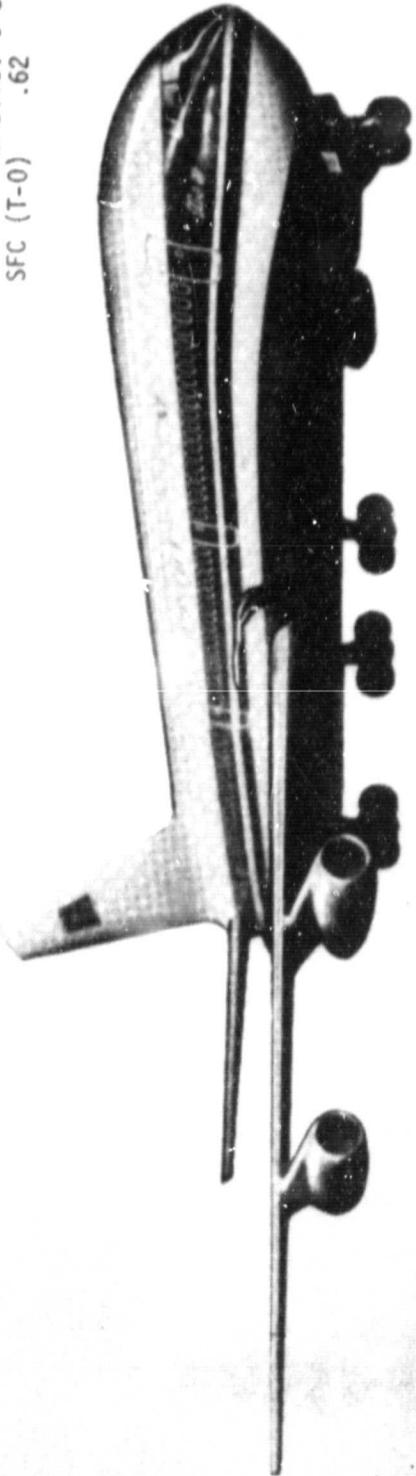


Figure A-4. - Model of the Ilyushin Il-86 aircraft.

IL 62M



TOWM 357,000 lbs
Pass 186
Range 4280 n.mi.
 M_{LR} .78
Engine 4 x 23,150 lb
Kuznetsov NK-8-4
SFC (T-O) .59

Figure A-5. - Ilyushin IL-62M aircraft.

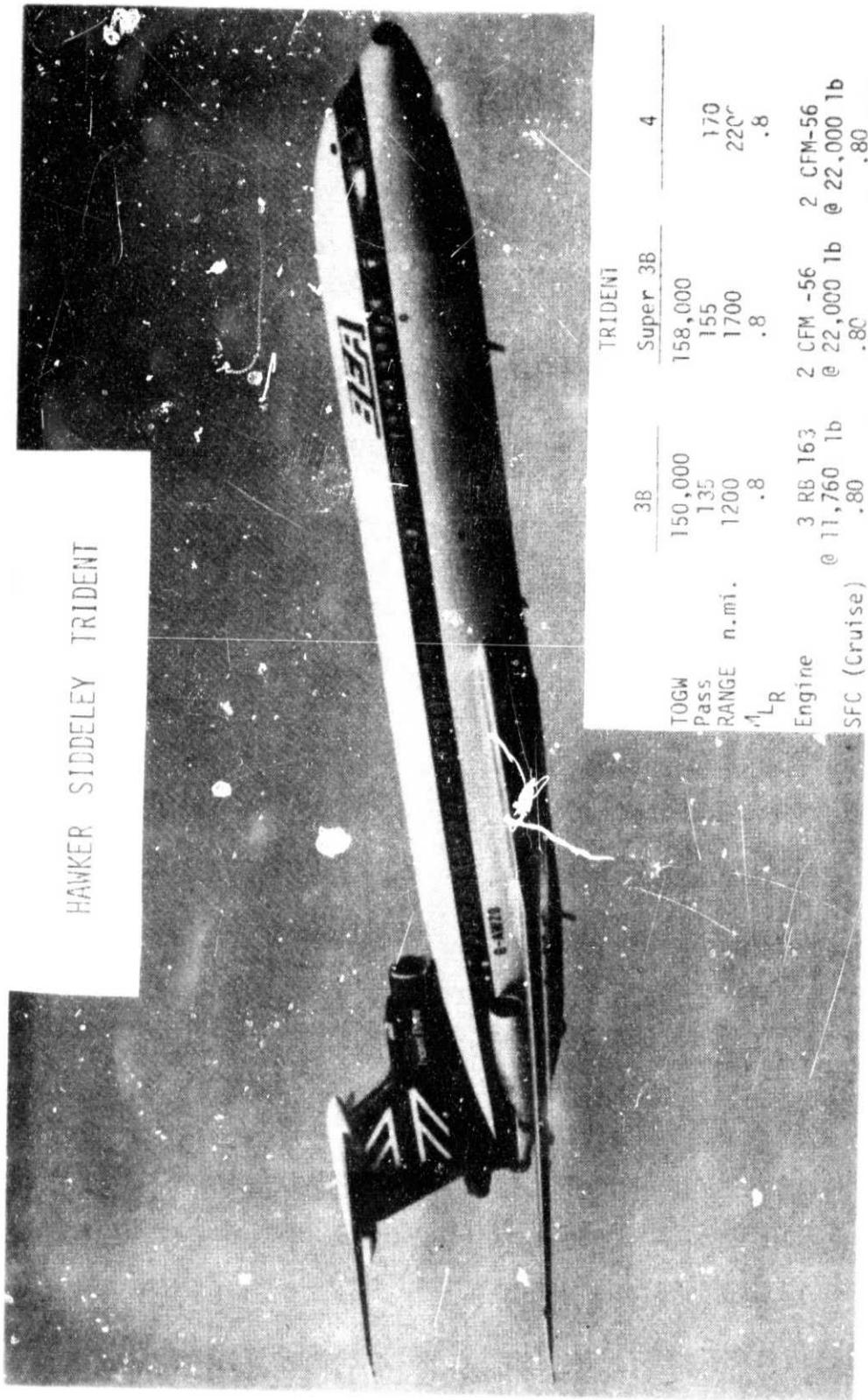
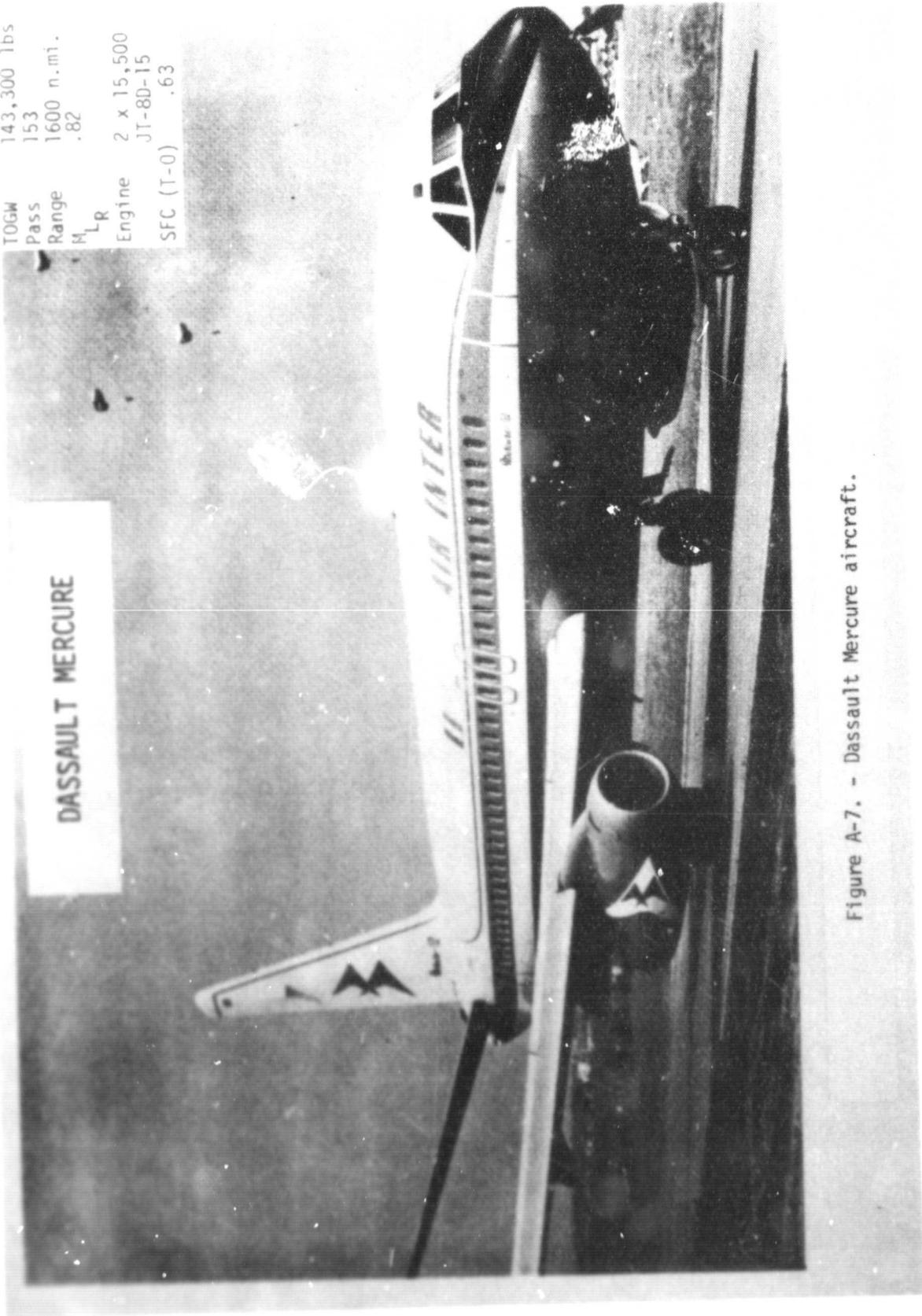


Figure A-6. - Hawker Siddely Trident aircraft.

DASSAULT MERCIURE

TOGW 143,300 lbs
Pass 153
Range 1600 n.mi.
 M_{LR} .82

Engine 2 x 15,500
JT-8D-15
SFC (T-0) .63

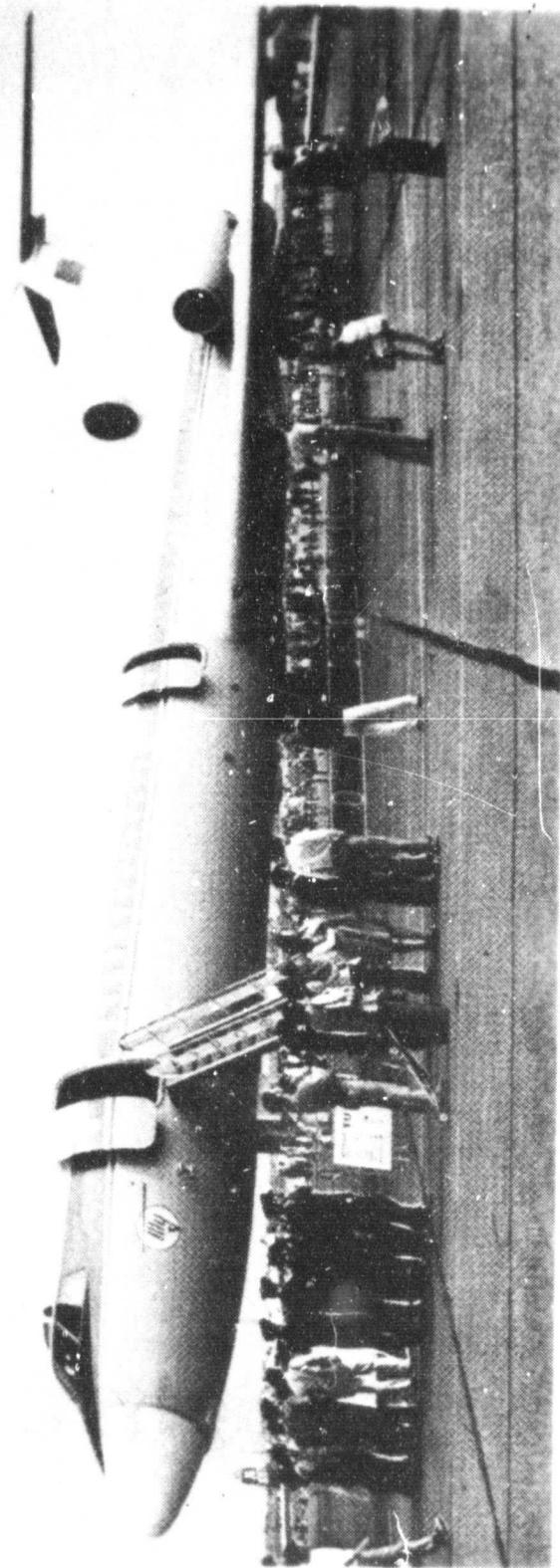


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Figure A-7. - Dassault Mercure aircraft.

TU 154

TOGW	198,400 lbs
Pass	164-178
Range	1360 n.mi.
M _L R	.80
Engine	3 x 25,300 Soloviev D-30K .49
SFC (T-0)	



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Figure A-8. - Tupolev TU-154 aircraft.

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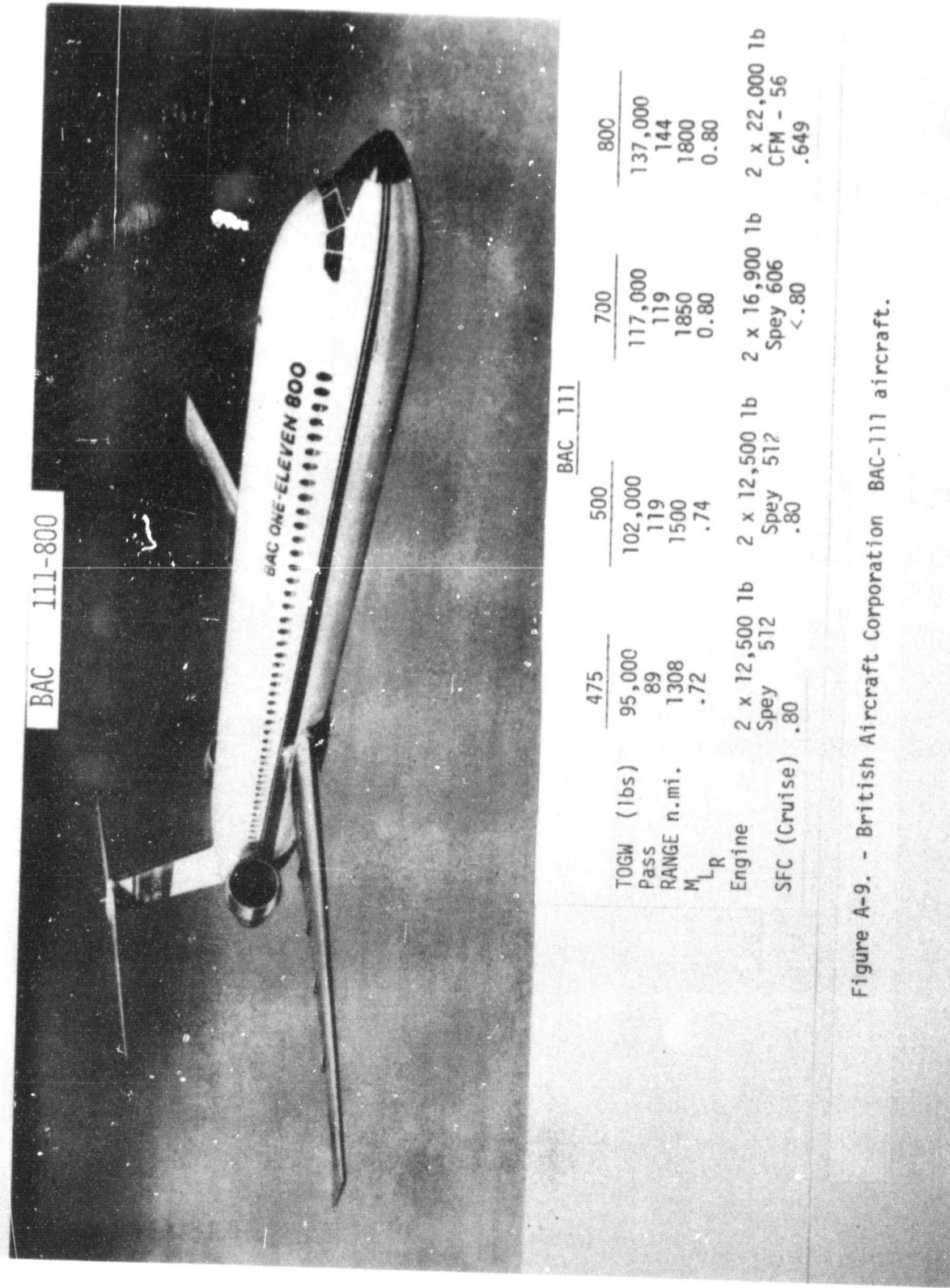
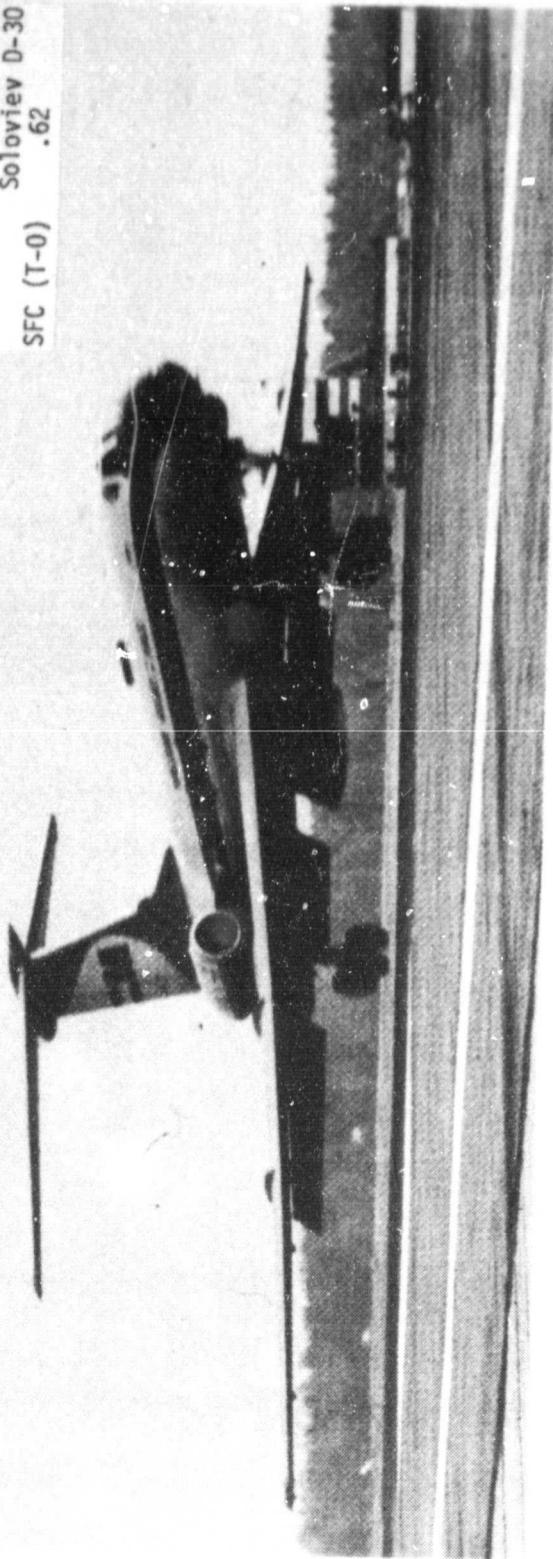


Figure A-9. - British Aircraft Corporation BAC-111 aircraft.

TU 134A

TOGW 103,600 lbs
Pass 76-80
Range 938 n.mi.
 $M_{L,R}$.75
Engine 2 x 15,000 lb
SFC (T-0) Soloviev D-30
.62

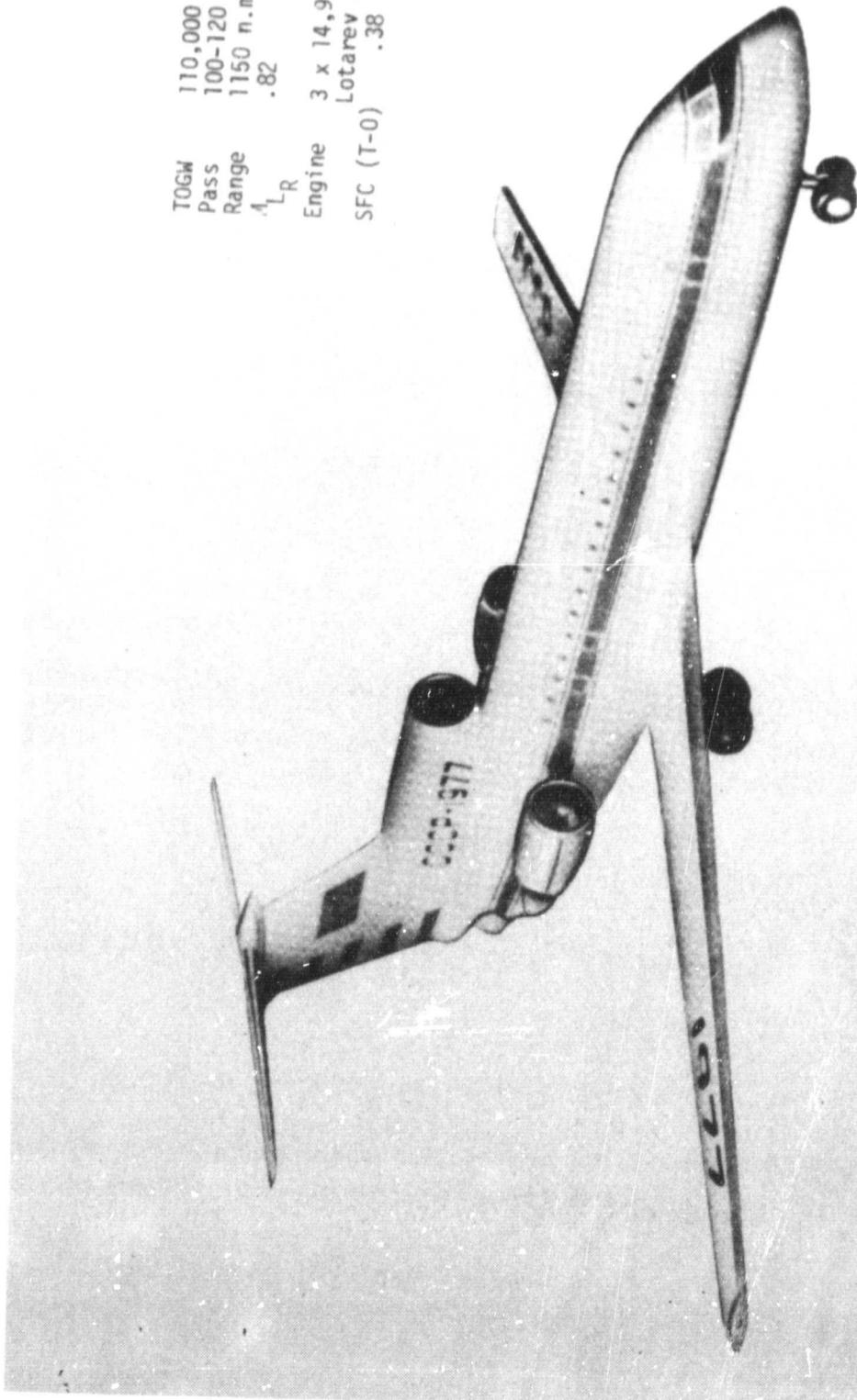


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Figure A-10. - Tupolev TU-134A aircraft.

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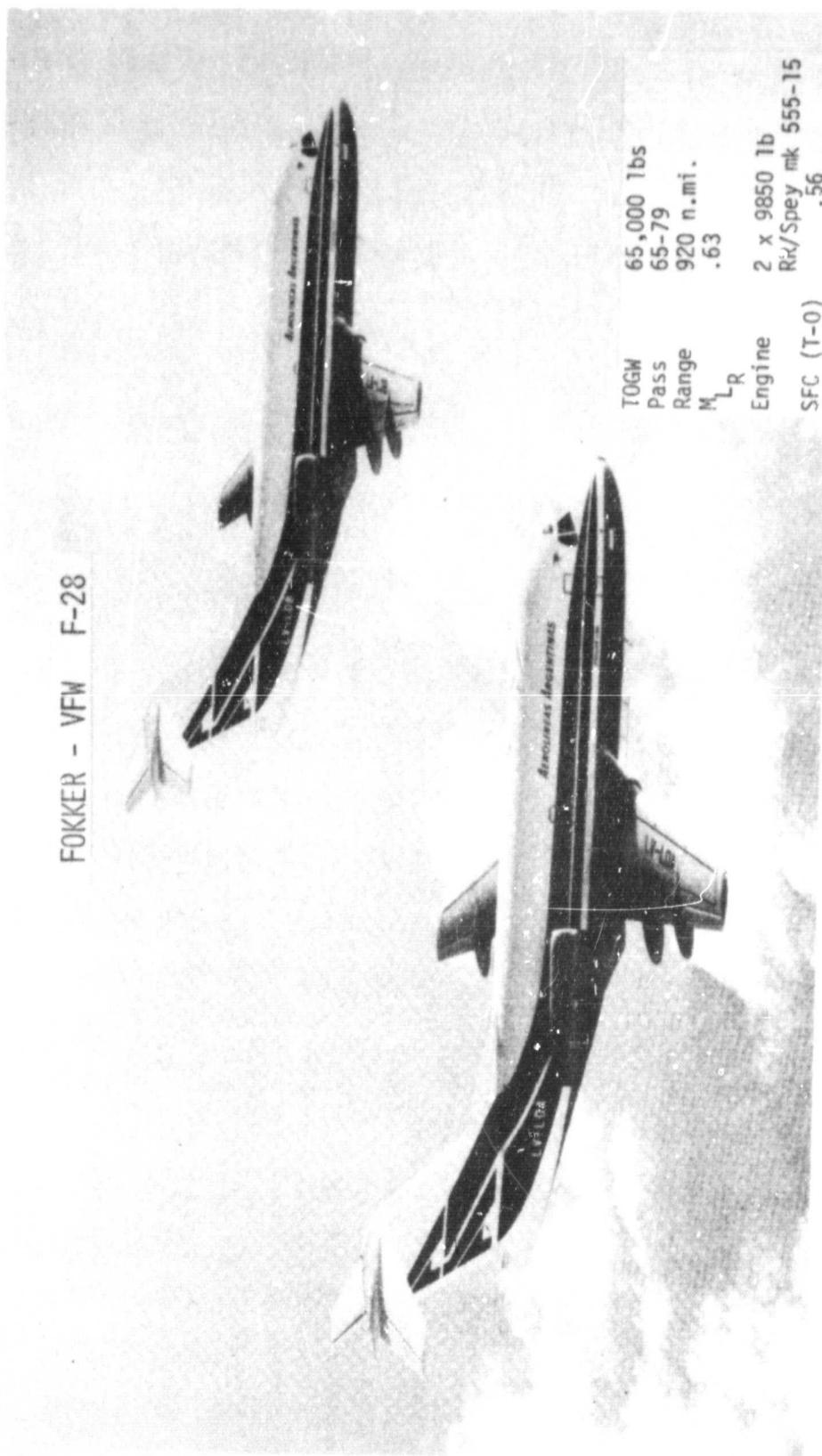
TOGW	110,000 lbs
Pass	100-120
Range	1150 n.mi.
A_{LR}	.82
Engine	3 x 14,900 lb Lotarev D36
SFC (T-O)	.38



YAK-42

Figure A-11. - Model of Yakovlev YAK-42 aircraft.

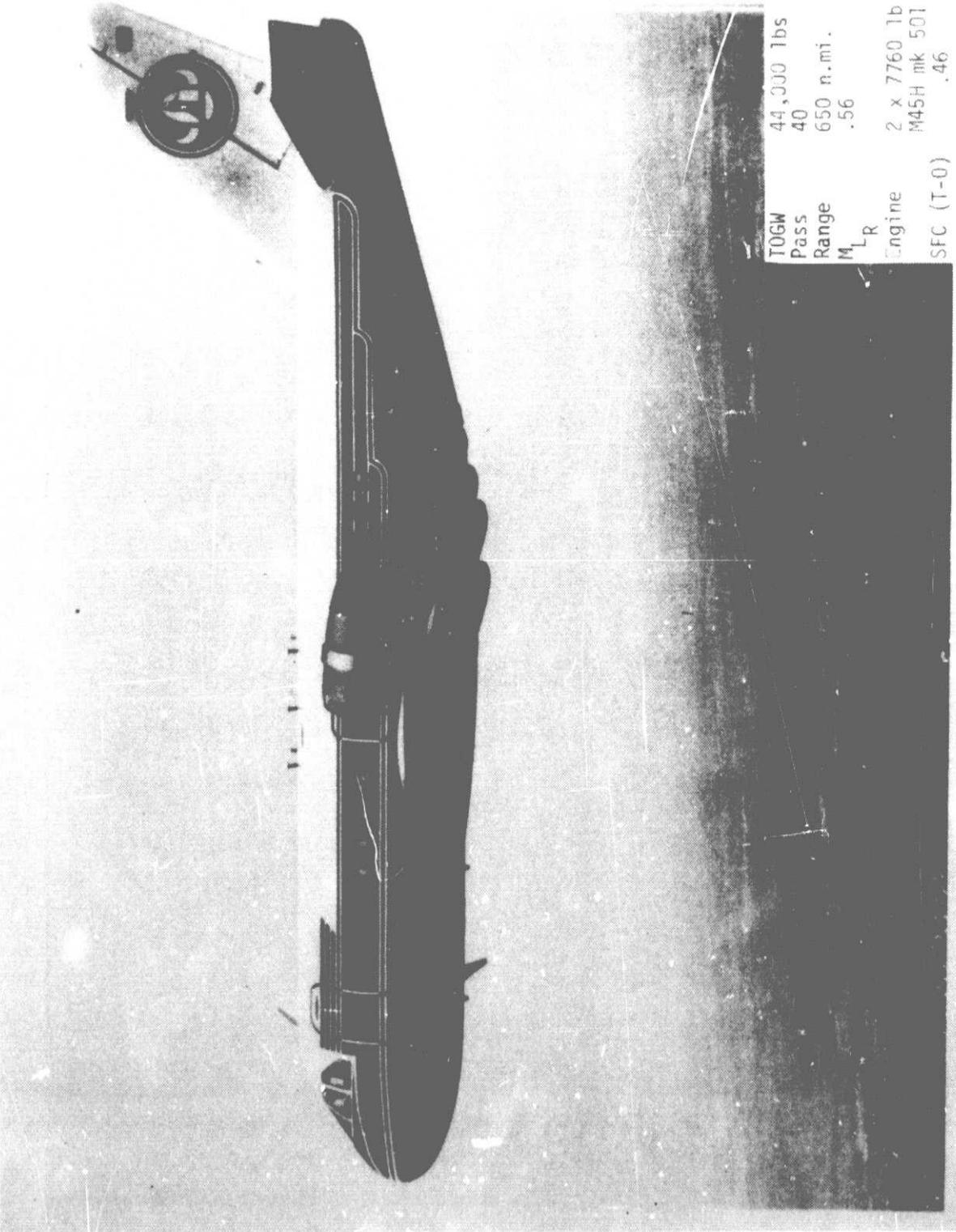
FOKKER - VFW F-28



TOW	65,000 lbs
Pass	65-79
Range	920 n.mi.
$M_{L,R}$.63
Engine	2 x 9850 lb Riv/Spey mk 555-15
SFC (T-0)	.56

Figure A-12. - Fokker-VFW F-28 aircraft.

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Figure A-13. - VFW-614 aircraft.

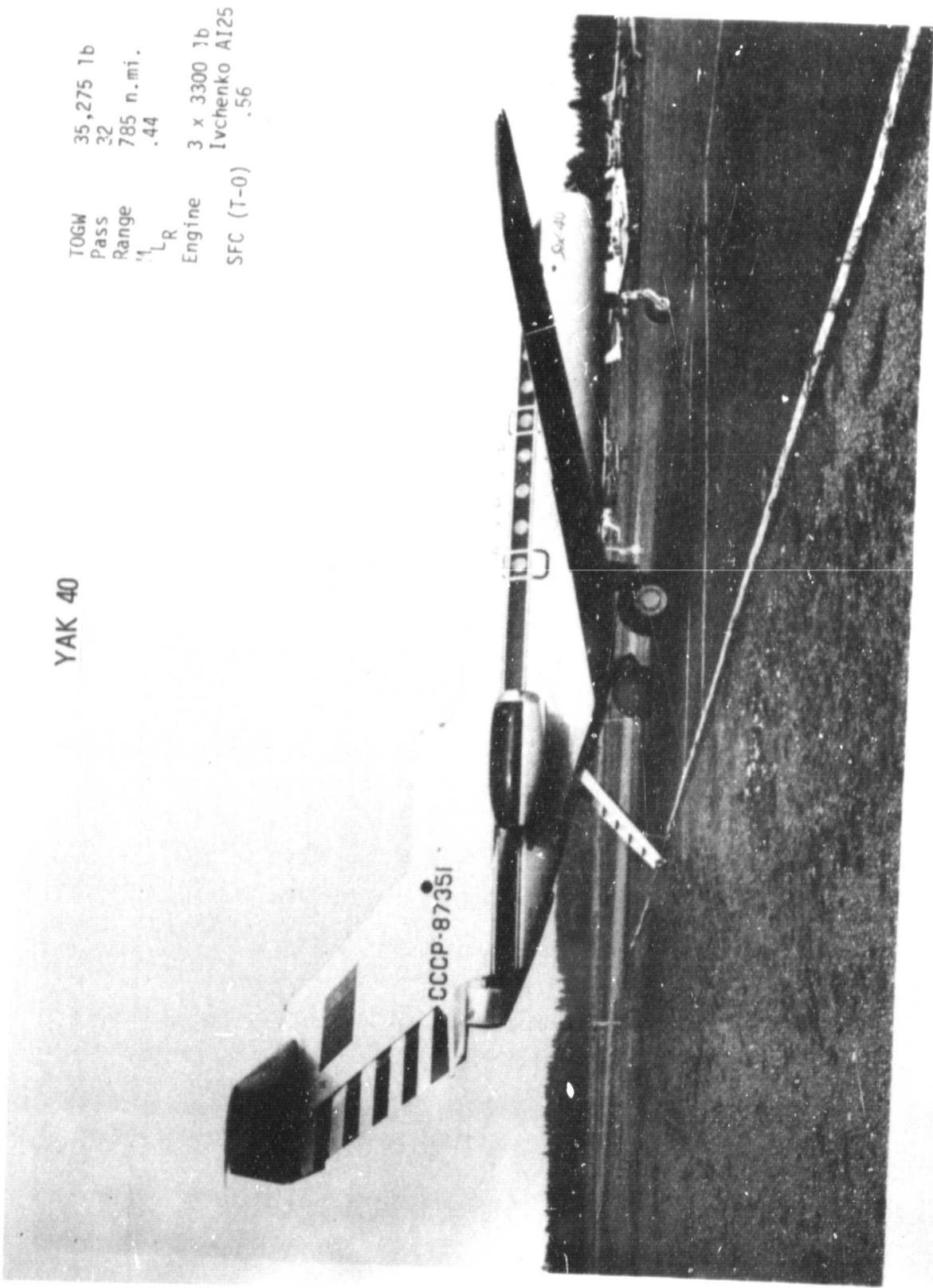


Figure A-14. - Yakovlev YAK-40 aircraft.